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Natural Resource Stewardship and Science

Landsat-based Monitoring of Landscape Dynamics at Indiana Dunes National Lakeshore

2007–2012

Natural Resource Report NPS/GLKN/NRR—2015/1073

ON THE COVER
A scene from Indiana Dunes National Lakeshore.
National Park Service photo, 2007.

Landsat-based Monitoring of Landscape Dynamics at Indiana Dunes National Lakeshore

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Abstract

The Great Lakes Inventory and Monitoring Network (GLKN) implemented the long-term land cover disturbance monitoring protocol at Indiana Dunes National Lakeshore (INDU) and completed the initial analysis in 2015. Disturbances, defined here as distinct changes in vegetation cover, are an important part of how this Great Lakes coastal system functions. Monitoring these disturbances through time will provide information regarding historic disturbance regimes compared to present and future conditions and trends. For this analysis, disturbances in and around INDU were delineated for six years (2007–2012) using a combination of Landsat satellite imagery and high resolution aerial photos. We employed a set of computer algorithms, collectively known as LandTrendr, in conjunction with an annual time series of Landsat imagery (one midsummer composite image, yearly since 1984) to track vegetation changes in and around the park. LandTrendr was used to identify apparent disturbances and the year of occurrence, after which high resolution imagery was used to validate the occurrence and determine the agent of change. Summary analyses showed that the dominant disturbances inside the park consisted of various wetland and forest restoration projects, with just over 100 hectares in area. The park experienced 3 times the amount of disturbances as outside the park based on percent of area, at 1.67% vs 0.63%. Disturbances outside the park consisted primarily of development, at 84% of total disturbance area. Though the total percent of area was very low, these types of disturbances result in permanent changes, further altering a landscape already heavily dominated by human uses. Watersheds nearest to the urban centers of Chicago, Illinois, and Gary, Indiana, all part of the Calumet River system, experienced the greatest percent of disturbance. Developed land cover classes already comprise more than 60% of these watersheds. The community of Valparaiso, south of the park is also growing rapidly, with development replacing agricultural land use.

Acknowledgments

The LandTrendr research group (http://landtrendr.forestry.oregonstate.edu/) at Oregon State and Boston University has been instrumental in the development of the Great Lakes Network's land use/land cover program by providing assistance and guidance in development of the land cover monitoring protocol, and in the implementation of the LandTrendr methods in land cover change detection. We thank M. Hart, G. Wagner, and J. Marburger for providing useful comments on this report.

List of Terms and Acronyms

APFO	Aerial Photography Field Office: a United States Department of Agriculture (USDA) Farm Service Agency (FSA) office located in Salt Lake City, UT.
APIS	Apostle Islands National Lakeshore
B&W	Black and white: airphoto type, commonly used prior to the 1990s.
CIR	Color infrared: the electromagnetic spectrum captured by a digital airphoto sensor (near-infrared, red, green).
DEM	Digital elevation model: a digital representation of ground surface topography or terrain.
Electromagnetic spectrum	The range of all possible frequencies of electromagnetic radiation. The electromagnetic spectrum of an object is the typical range of electromagnetic radiation emitted or absorbed by that particular object.
ETM+	Enhanced Thematic Mapper plus: one of the Earth observing sensors introduced into the Landsat program on 15 April 1999. http://landsat.usgs.gov/about_landsat7.php
GAP	Gap Analysis Program (http://gapanalysis.usgs.gov/)
GIS	Geospatial Information System: any system that captures, stores, analyzes, manages, and presents data that are linked to location.
HUC	Hydrologic unit code, an acronym used by USGS in reference to their National Hydrography Dataset. In general, lower numerical values refer to larger subwatershed sizes. For instance, a HUC 8 is much larger than a HUC 12 subwatershed.
INDU	Indiana Dunes National Lakeshore
ISRO	Isle Royale National Park
Landsat	The Landsat satellite family, and more specifically either Landsat 5 (launched in 1984) or Landsat 7 (launched in 1999), both with 30 m pixels (resolution). http://landsat.gsfc.nasa.gov/about/
LTS	In this report it refers to a Landsat Time Series; more specifically it refers to a collection of images by scene.
MISS	Mississippi National River and Recreation Area

List of Terms and Acronyms (continued)

NAIP	National Agriculture Imagery Program: acquires aerial imagery during the agricultural growing seasons in the continental U.S. Pixel resolution for this imagery typically ranges between 1 and 2 meters.
NBR	Normalized burn ratio: (near infrared - shortwave infrared)/(near infrared + shortwave infrared)
NHD	National Hydrography Dataset. www.nhd.usgs.gov
NLCD	National Land Cover Data: created by USGS to produce a consistent land cover map for the U.S using Landsat imagery. Currently there are three NLCD datasets; 1990, 2001 (versions 1 & 2), and 2006. http://www.mrlc.gov/
Panchromatic	Incorporates all wavelengths of visible light.
PIRO	Pictured Rocks National Lakeshore
RGB	Red, green, and blue: sometimes referred to as 'true color', it is the portion of the electromagnetic spectrum the film, or sensor, is quantifying.
SACN	Saint Croix National Scenic Riverway
SLBE	Sleeping Bear Dunes National Lakeshore
SLC	Scan Line Corrector: device on-board the Landsat 7 (ETM+) satellite which compensates for the forward motion of the spacecraft so that the resulting scans are aligned parallel to each other.
SLC-off	Scan Line Corrector – off: this device failed in 2003, creating data gaps in each Landsat 7 (ETM+) image acquired after 31 May 2003.
SWIR	Shortwave infrared band of information from the Landsat family of satellites (5, 7, and 8)
TM	Thematic Mapper: one of the Earth observing sensors introduced into the Landsat program on 1 March 1984. http://landsat.usgs.gov/about_landsat5.php
USGS	United States Geological Survey
VOYA	Voyageurs National Park

Introduction

Disturbance Monitoring Overview

Monitoring changes in land cover and land use has long been recognized as an important part of monitoring landscape processes (Cohen and Goward 2004). Data obtained from disturbance detection and monitoring have been used in ecosystem modeling of carbon (Law et al. 2004, Turner et al. 2006, Potapov et al. 2009, Powell et al. 2010); for mapping fire extent, severity, and recovery (Veraverbeke et al. 2010, Chen et al. 2011, Meigs et al. 2011); for evaluating policy effects on land use (Kennedy et al. 2012); and for modeling the effects of disturbances on watershed characteristics (Eshleman et al. 2009, Deel et al. 2012). Several techniques for detecting and delineating landscape change have emerged as remote sensing and GIS technologies have evolved (Cihlar 2000, Coppin et al. 2004, Lu et al. 2004, Radke et al. 2005, Wulder and Franklin 2007). Table 1 shows a summary of the four most common types of change detection, including potential benefits and disadvantages of studies using these various techniques.

Previous Landscape Dynamics Studies in the Western Great Lakes Region

Previous landscape dynamics studies in the region have focused on large-scale changes in land cover and land use using moderate resolution imagery such as Landsat (30 m pixels). Wolter et al. (2006) examined land use and land cover change in the U.S. Great Lakes basin for one time period (1992–2001) using two generations of the National Land Cover Dataset (NLCD). The study found that 2.5% of the watershed experienced change, with forest and agriculture categories experiencing the largest declines in area (approximately 2.3%). In addition, 49.3% of the changes were transitions from undeveloped to developed land, with the greatest percentage of the overall watershed change occurring within 0–10 km of the shoreline. More recently, Stueve et al. (2011a) investigated the amount of disturbance in the Lake Superior and Lake Michigan basins from 1985 to 2008 using Vegetation Change Tracker (VCT). They found that 3.2% of the land (0.23%/yr) was disturbed in the upper Lake Michigan basin during 1985–1999, and 2.4% of the land was disturbed during 2000–2008 (0.27%/yr). This study was performed on an extremely large scale, providing less information on smaller subunits of the Lake Michigan watershed.

Brown (2003) investigated the relationship and trends in land use and forest cover on private parcels in the Upper Midwest (the northern forested regions of Minnesota, Wisconsin, and Michigan) from 1970 to 1990 and found that land development increased in all 106 counties. In addition, the percentage of land in agriculture declined between the 1980s and 1990, but held steady in some counties when observed over the entire time period (1970s to 1990). This could reflect the conversion of previously-cleared forest lands for agriculture back to a forested cover type. In four national forests in northern Wisconsin and Michigan, a separate study (Stueve et al. 2011b) focused on studying “intermediate” wind disturbances, those not generally studied due partially to the fact that they are not easily detected with most remote sensing techniques. They found that these disturbances rivaled the amount of land disturbed by large, infrequent disturbances (e.g., fires or extreme wind events).

Table 1. Comparison of common methods used for change detection. The method used in this report is a type of spectral trajectory analysis.

Method	Description	Pros	Cons	Studies
Airphotos	Manual interpretation of available photos to delineate changes on the landscape. Also commonly used to classify land cover and land use.	Very detailed	Time intensive, very subjective based upon interpreter.	(Rutchey and Vilchek 1999, Lillesand and Kiefer 2000, Harvey and Hill 2001, Maheu-Giroux and de Blois 2005, Morgan et al. 2010)
Two date subtraction	Subtract the spectral values of one year of imagery from another year of imagery. A threshold is then developed to separate real change from ‘false’ change.	Simple, quick	Due to only two images being used, a large number of ‘false’ changes are detected due to sensor aberrations.	(Aldrich 1975, Coppin and Bauer 1995, Cohen et al. 1998, Healey et al. 2005, Kennedy et al. 2007a)
Spectral trajectory analysis	Detect temporal patterns or ‘trajectories’ in the sequence of imagery.	Largely removes year-to-year variation. Capture longer overall trends and more subtle disturbances.	Requires robust radiometric normalization. May involve complex statistical analysis to detect change.	(Kennedy et al. 2007b, Huang et al. 2009, Huang et al. 2010, Kennedy et al. 2010b, Schroeder et al. 2011, Sonnenschein et al. 2011, Stueve et al. 2011a, Kennedy et al. 2012, Zhu et al. 2012)
Object orientated analysis	Relatively new technique incorporating spectral information (tone, color) as well as spatial arrangements (size, shape, texture, pattern, association with neighboring objects).	By including information from neighboring pixels (among others), it is beginning to approach human interpretation.	Works better with high resolution imagery and results vary depending on imagery used for analysis.	(Hay et al. 2003, Benz et al. 2004, Laliberte et al. 2004, Walter 2004, Wang et al. 2004, Yu et al. 2004, Desclee et al. 2006, Heurich et al. 2010, Lu et al. 2011)

Landscape perturbations produce ripple effects in multiple natural processes. Fitzpatrick et al. (1999) studied the effect of the major shift in land cover and land use in northern Wisconsin watersheds since the late 1800s, and saw large changes in the sedimentation load and flow dynamics. Verry et al. (1983) studied the effect of forest composition within watersheds and how this affected the spring runoff events. They found that forested watersheds comprised of mixed age forest helped buffer the spring runoff events. Also, resulting effects of landscape disturbances such as fragmentation and land cover changes have been found to affect (both positively and negatively) the abundance of rare and endangered species; biodiversity and habitat for birds, amphibians, and other animals; water quality; and in-stream habitat for fish (Ward 1998, With 2002, Fahrig 2003).

Because landscape disturbances can affect a broad range of natural resources, being cognizant of the changing landscape in and around Indiana Dunes National Lakeshore will help inform resource managers at the park about pressures affecting the areas under their jurisdiction.

Although many landscape dynamics studies have been performed in the upper Great Lakes region, there is a lack of this type of research in the Indiana Dunes National Lakeshore vicinity. In addition, due to the culture of research conducted by many colleges and universities, many of these studies are supported by one-time funding ("soft money") from governments and organizations; thus, they are often limited to a duration of only two or three years. This is one of the many reasons the National Park Service (NPS) Inventory and Monitoring program was developed: to provide consistent, long-term monitoring of ecologically significant parameters affecting national park lands

Study Area

The study was conducted on the southern end of Lake Michigan in Lake, LaPorte, and Porter counties in Indiana, portions of Cook and Will counties in Illinois, and a small portion of Berrien County in Michigan (Figure 1). Indiana Dunes National Lakeshore (INDU) consists of an East and West unit along the lakeshore, and five smaller disjunct units (Heron Rookery, Hobart Prairie, Calumet Prairie, Gaylord Butterfly Preserve, and Pinhook Bog). The study area was designed to include all of the watershed catchments contributing surface water flow to the park. We used the 10-digit Hydrologic Unit Code (HUC) delineations to define those watershed boundaries (United States Geological Survey and United States Department of Agriculture 2013). The park lies within a largely urban landscape, with Gary, Indiana, to the west, and Michigan City, Indiana, to the east. The landscape to the south and within the watersheds flowing toward the park consists largely of a flat to rolling landscape predominantly in agriculture and rural development. Over 164,000 ha of land were included in the study, 4% of the land being located within the INDU boundary (Table 2).

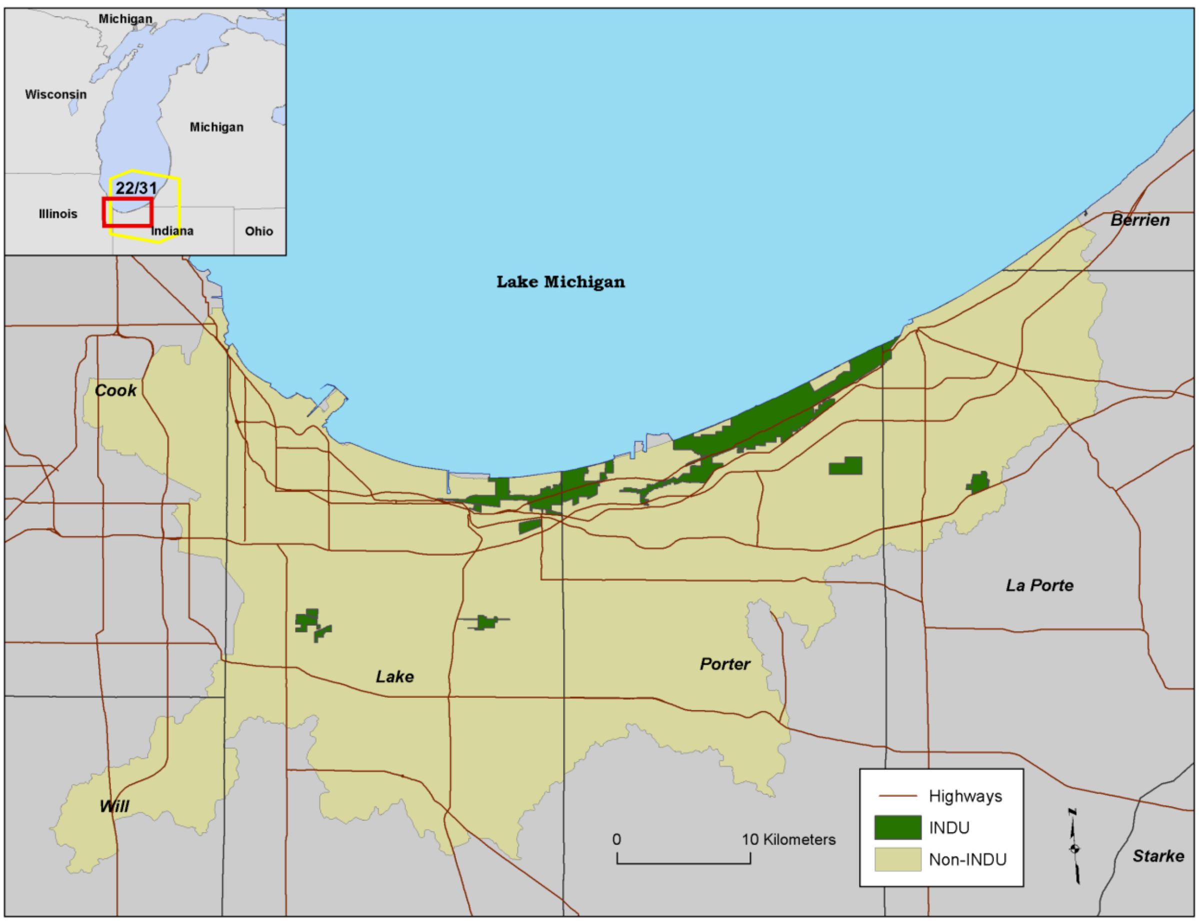

Figure 1. Study area for long-term monitoring of landscape-scale disturbances in and around Indiana Dunes National Lakeshore, Indiana. The inset shows the extent (yellow line) of the Landsat scene (22/31) processed and analyzed for this report. The larger map shows park administered lands (dark green) and the extended analysis area (light tan) outside the park.

Table 2. Land area of each analysis region and the percent contribution to the overall analysis area. “INDU” is all land within the administrative boundary, and “Non-INDU” refers to all land outside the administrative boundary. (Park area includes Indiana Dunes State Park.)

Analysis area	Size (ha)	Percent of analysis area
INDU	6,413	4
Non-INDU	157,593	96
Total	164,006	100

Vegetation

The following summaries of land cover types are based on the 2006 National Land Cover Dataset (Fry et al. 2011) (Figure 2). The largest land cover type within the park boundary is comprised of wetlands (herbaceous and forested) at 41.3%, and includes the Great Marsh and Cowles Bog. The second largest cover type is forest, primarily deciduous, at 29.7%. Almost 15% of the area is in developed classes, (open space, and low, medium and high intensity), though the majority of that is the open space class (60%). The remaining 14% of the park is in shrub, herbaceous, barren land (largely dune) classes, and water (Figure 3).

Overall, developed land classes (combined open space, and low, medium and high intensity) comprise the largest amount of land outside the park within the area analyzed, totaling 46%. INDU is adjacent to the large cities of Chicago, Illinois, and Gary and Michigan City, Indiana, all located on the south shore of Lake Michigan. There is a substantial amount of agricultural land, 16.2% of the area, mostly to the south and east of the park, though development is slowly replacing agricultural land use. Forest comprises 12.7%, with the remaining 25% in wetland (8.6%), herbaceous, shrub and pasture (14.6%) cover classes, and water (1.7%) (Figure 3).

The sharp differences in land cover between the park and surrounding area highlights the park’s existence as an isolated natural area refuge within a sea of human dominated land use (Gimmi et al. 2011). There are few corridors for wildlife movement, migration of amphibian species, exchange of seed stock, or dispersal for vegetation. Management of park natural resources becomes more challenging in this context.

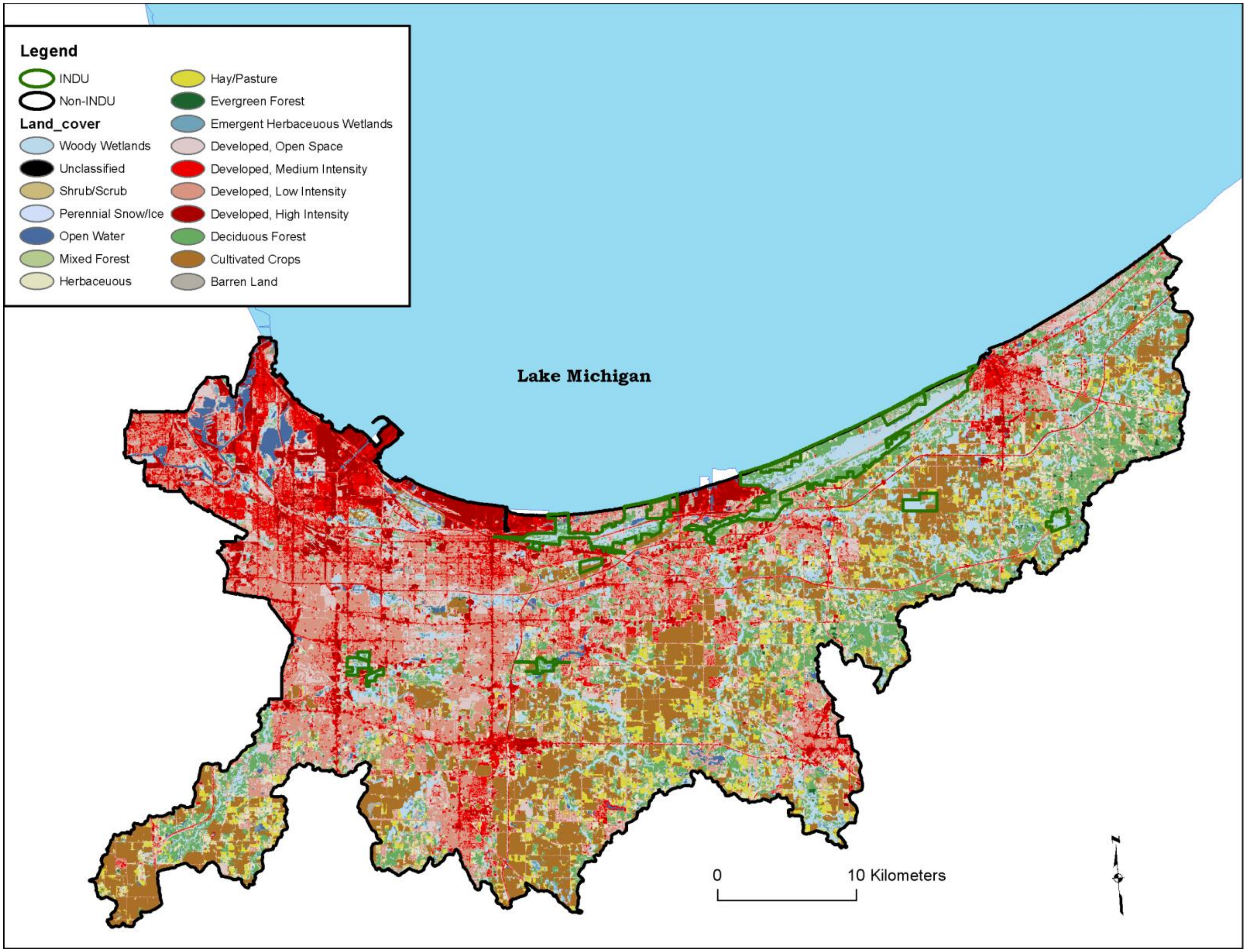

Figure 2. Land cover classes within the analysis areas (INDU and Non-INDU). Data from 2006 NLCD.

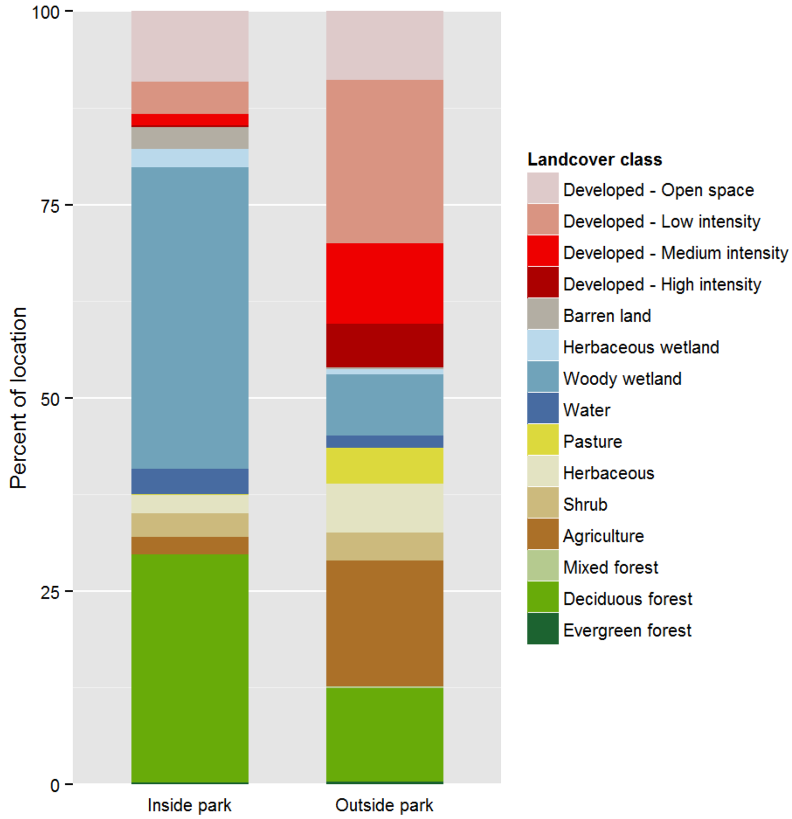

Figure 3. Relative abundance of land cover classes within the analysis area. Data from 2006 NLCD.

Ownership

For all other network parks analyzed thus far, we have summarized disturbances based on land ownership patterns using the National Gap Analysis Program (GAP). Ownership information from the GAP within the INDU analysis area is only categorized to a few conservation status classes, and 'unknown'. It is apparent that 'unknown' is private land, though there is no distinction between commercial vs residential, or other private designations. Thus, in this report we summarize disturbance patterns based on the few public/conservation lands classes and private lands (Figure 4).

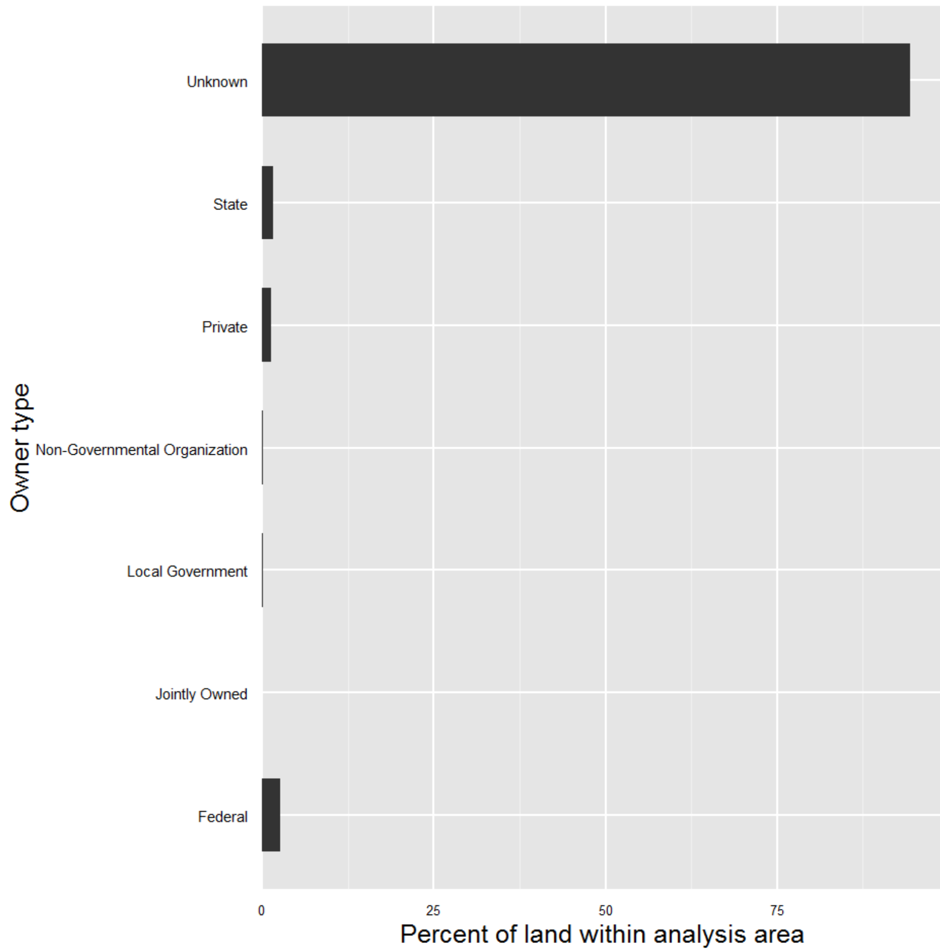

Figure 4. Spatial distribution of land ownership within the analysis area. Data from the National GAP Analysis dataset.

Watersheds

We used watershed boundaries from 10 digit hydrologic unit codes (HUC 10) to define the overall analysis area. There were seven HUC 10s included within the analysis area, those relevant to surface water flow contribution into the park (Figure 5).

The largest watershed within the analysis area is the Deep River-Portage Burns Waterway, with over 28% of the area, followed by the Plum Creek-Little Calumet River, with just over 15% (Figure 6). The other five watersheds collectively occupy the remaining 57% of the land. The hydrologic unit code boundaries are not necessarily synonymous with true watersheds (with flow converging to a single pour point), but rather are subdivisions that often group stream systems not directly connected. This is common along the Great Lakes, where several streams that flow into the big lake are grouped into 'Frontal' watershed delineations, such as Calumet-Frontal Lake Michigan. The watersheds around INDU are particularly difficult to ascertain as there has been significant human alteration from ditching, channelizing, and re-routing of stream courses.

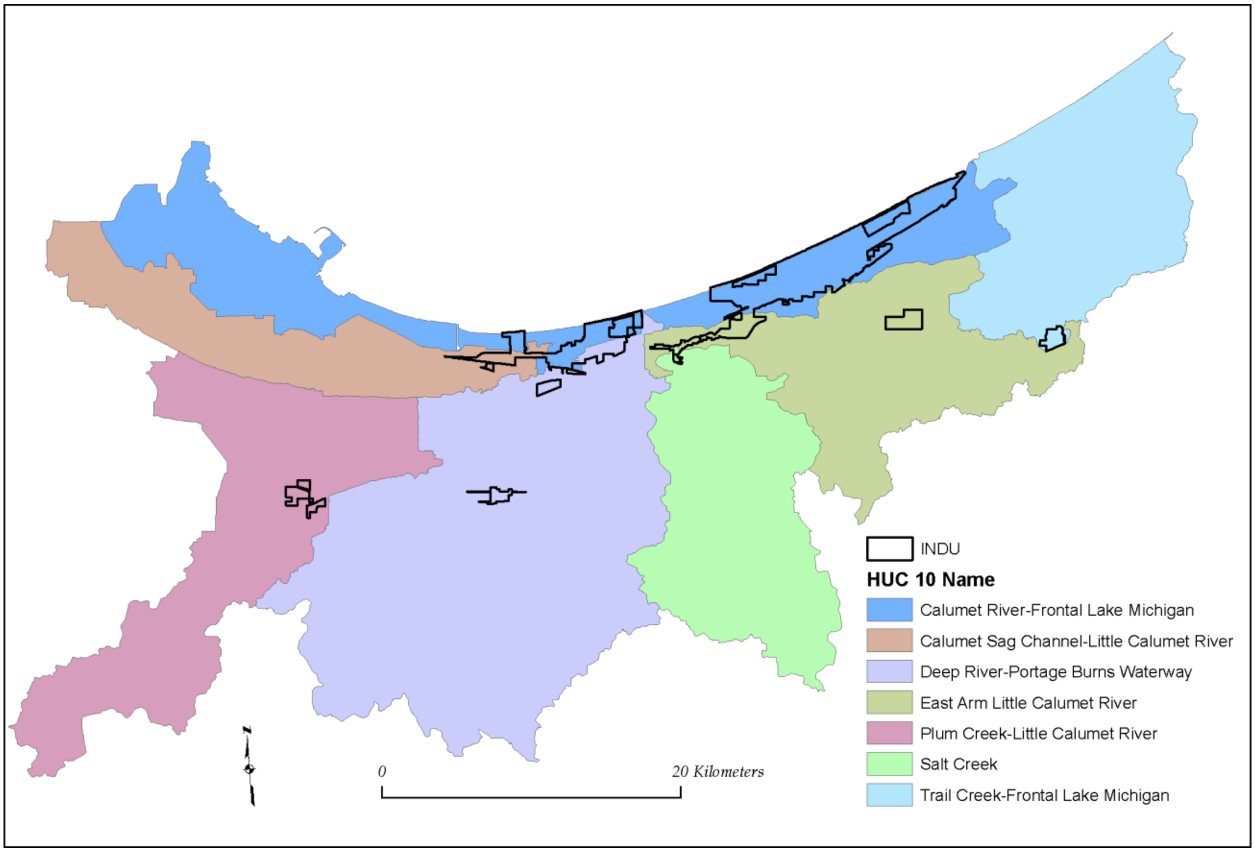

Figure 5. Spatial distribution of watersheds (HUC 10) within the analysis area. Data from the USGS Watershed Boundary Dataset.

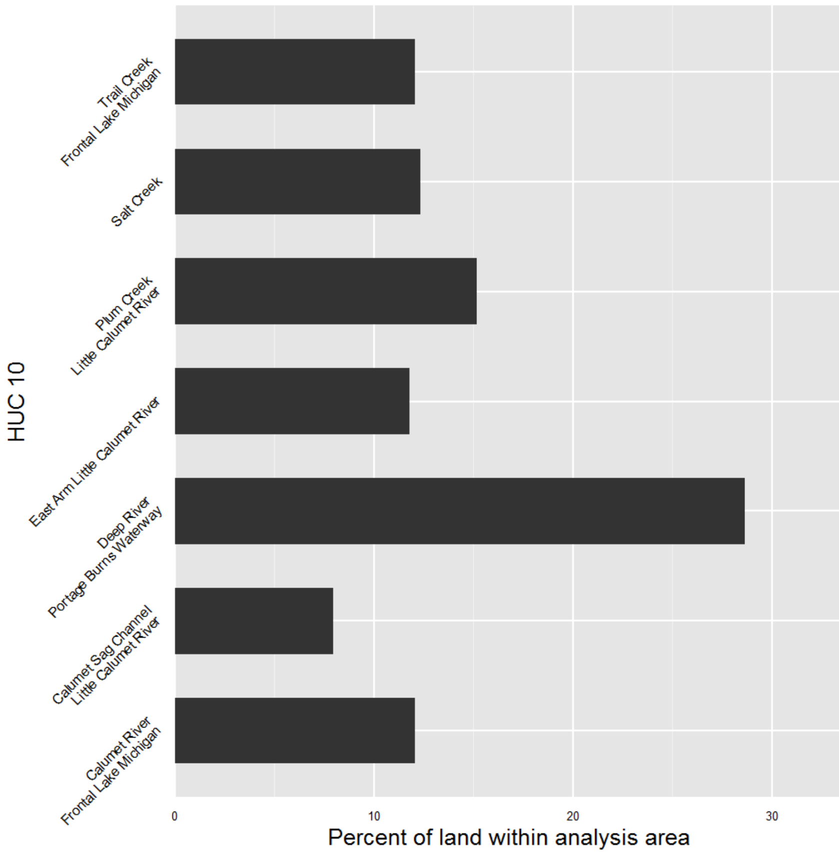

Figure 6. Percent of land within the analysis area grouped by watershed using HUC 10.

Another interesting pattern is to examine land cover type distribution within these watersheds. Watersheds closest to Lake Michigan are the most urbanized. For example, developed classes within the Calumet Sag Channel-Little Calumet River comprise 86% of the total area. The Calumet River Frontal Lake Michigan and Plum Creek-Little Calumet River watersheds are both over 60% in developed classes (Figure 7).

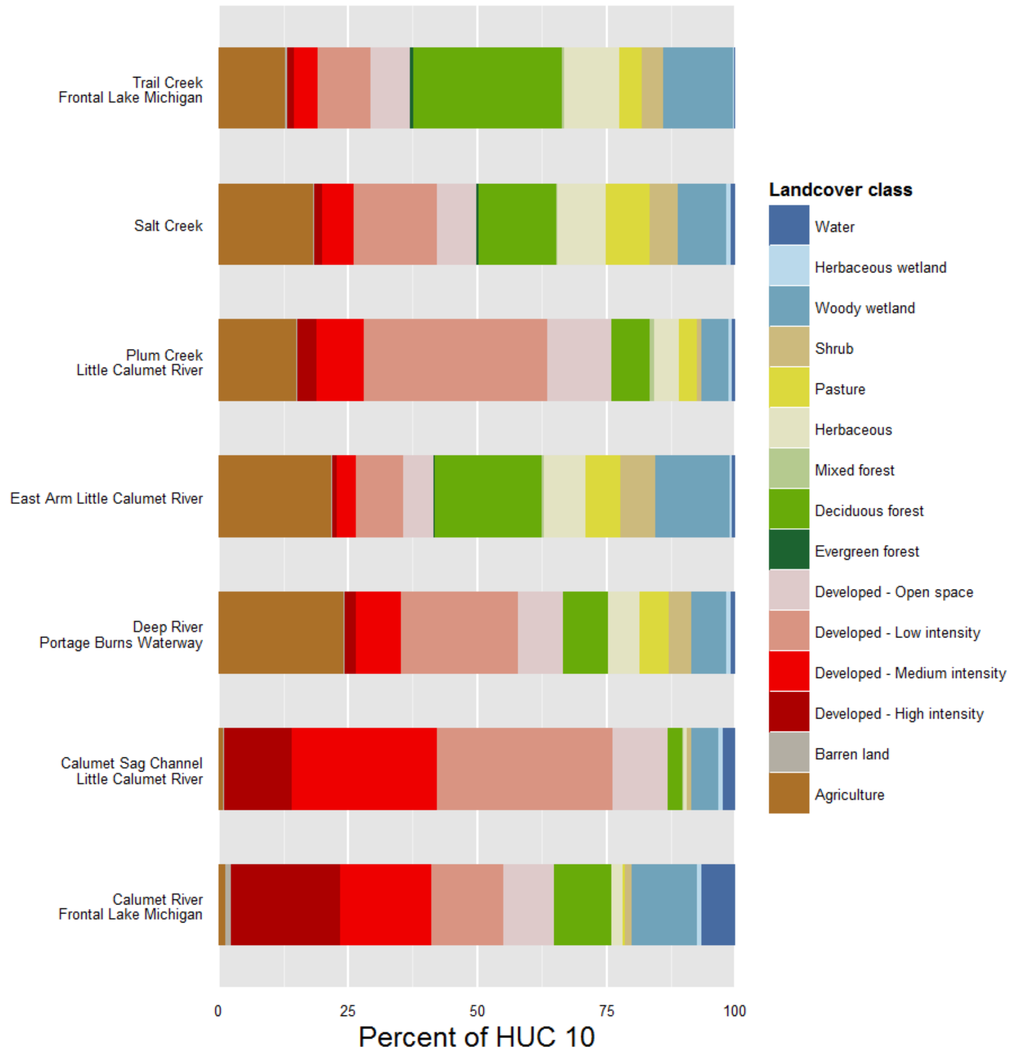

Figure 7. Percent of watershed area in various land cover classes based on 2006 NLCD.

Methods

GLKN Approach to Monitoring Disturbances

Given the choices in disturbance monitoring, the Network spent three years working with various collaborators to evaluate the advantages and disadvantages of various techniques. In addition to being accurate, the method chosen by GLKN needed to be cost-efficient to allow other Network programs to operate and to allow the possibility of monitoring additional vital signs in the future. One of the approaches considered during protocol development used direct airphoto interpretation of vegetation classes and land use. This method required extensive field validation for accuracy assessment and was deemed too subjective and field-intensive for long-term monitoring. Another approach under consideration included the use of high resolution aerial photos with object-oriented software to delineate land cover classes which would then be monitored through time. This approach was not chosen due to the lack of a consistent source of high spatiotemporal resolution airphotos, and lack of repeatability. In the end, a consistent, unbiased approach was chosen that relies on freely available, moderate resolution (30 m) satellite imagery (Landsat). The Landsat archive contains imagery from 1984 to present, the longest record of satellite imagery available today.

To detect and delineate landscape changes we used a method called LandTrendr (Landsat-based detection trends in disturbance and recovery), which was developed by a group of research scientists at Oregon State University (Kennedy et al. 2010a). Briefly, LandTrendr is the process of capturing interesting features (disturbances) while removing the background, or noise. Sources of this noise include variation in atmospheric condition, changes in sun angle illumination, and small phenological changes. Details of the LandTrendr process can be found in Kennedy et al. (2010a). Lastly, this method also proved to be the most cost-efficient program for the Network in terms of cost per hectare. The cost of implementing the protocol at INDU was only 8¢ per hectare, considering only staff time is included. We may still assist in acquisition of aerial photography opportunistically, as regional or state programs collect imagery, but these acquisitions have much broader application than just land cover monitoring.

Following methods outlined in the landscape dynamics protocol (Kennedy et al. 2010a), we identified and categorized changes in land cover and land use for the years 2007 through 2012. Disturbances were identified both within the park and in an area adjacent to the park to aid in placing the park in a larger landscape context. We chose to monitor park lands plus seven watersheds (Hydrologic Unit Code 10) adjacent to the park, totaling about 164,000 hectares (see Figure 1). The size of the analysis area was determined by including all watersheds with contributing area flowing toward INDU, but also limited by the amount of time available for validating disturbances. The ability to monitor large areas of land outside the park is due to our use of Landsat imagery as the foundation, allowing free access to multiple years of intermediately-scaled imagery.

Image Data and Processing

One Landsat scene (22/31) was acquired for analysis (see inset of Figure 1). The word “scene” refers to the path/row address that is recorded every 16 days by the Landsat satellite; data recorded on a specific date are referred to as an “image.” Landsat imagery was downloaded from the Landsat data archive via the U.S. Geological Survey's (USGS) GLOVIS website (http://glovis.usgs.gov/). To minimize the effect of phenology, imagery was selected in a two-month window (July and August) during the peak growing season (Figure 8). For each year since 1984, the goal was to acquire enough imagery in the optimal phenological window such that one cloud-free composite for each year covering the entire study area could be used in the analysis. To aid in the production of the cloud-free composite, we also acquired a number of scan line corrector-off (SLC-off) images. These images include strips where there are no data due to a Landsat hardware malfunction, but nonetheless can be used to fill in critical gaps in the time series (http://landsat.usgs.gov/products_slcoffbackground.php). In total, 53 images were downloaded and processed for analysis. Each collection of images by scene will be referred to as a Landsat time-series (LTS).

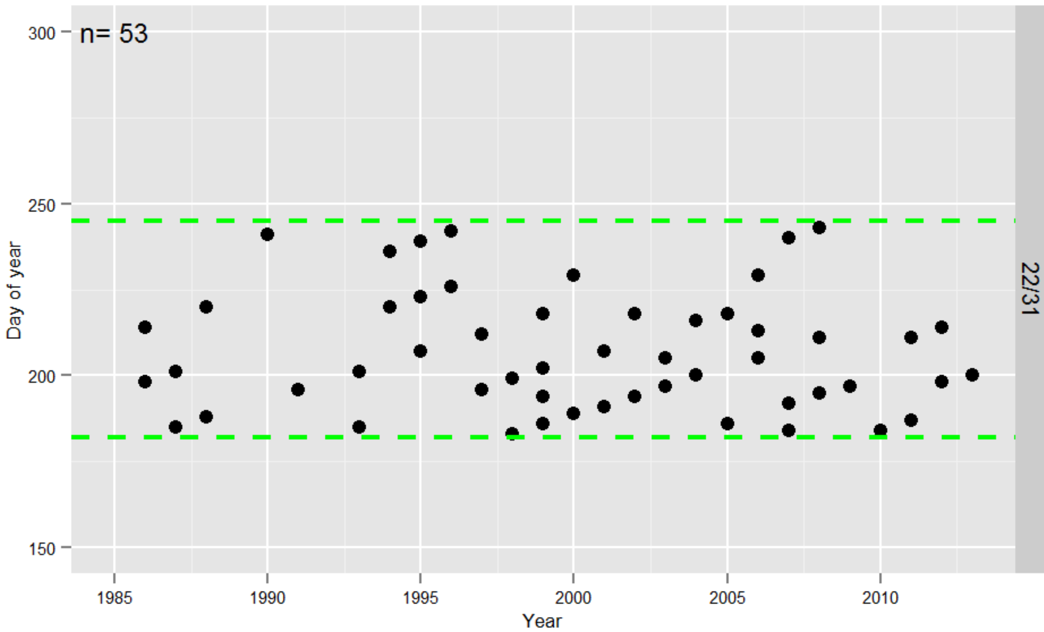

Figure 8. Day and year of Landsat images used for analysis for scene 22/31 with green dotted lines delineating the time period between 1 July and 31 August.

Preprocessing of images (atmospheric correction and cloud screening) within each scene followed details given in Zhu et al. (2012) and is briefly summarized here. We have assumed that the level of Landsat images used (L1T) are already precisely registered and that sub-pixel misregistration will not influence our analysis. All images were atmospherically corrected using the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS), which uses the 6S radiative transfer approach (Vermote et al. 1997, Masek et al. 2006). Missing pixel data were also masked for images from the ETM+ sensor after the onset of scan line errors (2003 and later). We used the cloud masking algorithm (Fmask) defined in Zhu and Woodcock (2012), which identifies clouds, cloud shadow and snow based on a time series of Top of Atmosphere reflectances of each pixel. The registered, atmospherically-corrected, cloud-screened images in the LTS served as the foundation for subsequent processing.

LandTrendr algorithms operate on a single detection index which can be any single band of information. Although the algorithm itself can only be run on a single detection index, LandTrendr can be run multiple times, on different indices, then combined into one disturbance layer. For this analysis we used the normalized burn ratio (NBR) and the short-wave infrared (SWIR) band. In our experience in northern hardwood forests, the SWIR band does better at delineating forest clearcuts, while NBR is more sensitive to subtle disturbances such as partial forest harvests. For the remainder of the report, we will refer to these indices collectively as disturbance indices (DI).

After the DI's are chosen, a composite image is created. The image data from this scene was converted to disturbance index values and matched on a pixel-by-pixel basis with the cloud mask. If the pixel was pre-determined to be part of a cloud, the pixel was not used. When multiple images from a given year were available, the image closest to the median date of the LTS in that scene was preferred, but if the pixel was again masked (cloud, cloud-shadow, or missing data), the pixel value from the image next-closest to the median was used. This was repeated as necessary until an unmasked pixel was available or until no more images were available.

The time-series of these source data was then sent to the segmentation algorithms, which are controlled by a number of parameters affecting the balance between over- and under-fitting. The first phase of segmentation is to determine the vertex years that define the end points of segments, and the second phase is to determine the best straight-line trajectory fit through those vertices using a flexible mix of either point-to-point or regression lines. The values returned from the segmentation algorithm are the yearly source data (representing the unmasked DI value for that pixel in each year), the vertex years, the fitted DI values for those vertices, and the yearly fitted DI data (the DI value of each point in the segments describing the trajectory). These data were written out as separate files to be used by subsequent mapping algorithms. A diagram describing the segments for each pixel is shown in Figure 9.

Disturbances for the area were derived from the vertex files in several steps. Segments were accepted for further processing only if their relative magnitude value was greater than a pre-defined threshold parameter. This filtering is an effective means of reducing false changes from overfitting of anomalous or ephemeral spectral features in the time-series. Lastly, the LandTrendr pixel outputs are grouped into patches based on the year the change began and the duration of change. For this protocol, the patches are first screened by duration, so that the dataset only includes pixels that experienced rapid change of <4 years in duration. The remaining pixels are then grouped into patches based on the first year of observed change, even if the event occurred later in the previous year. Patches must be nine pixels (0.8 ha) or larger to be included in the monitoring dataset, hence we can only reliably capture disturbances larger than 0.8 ha.

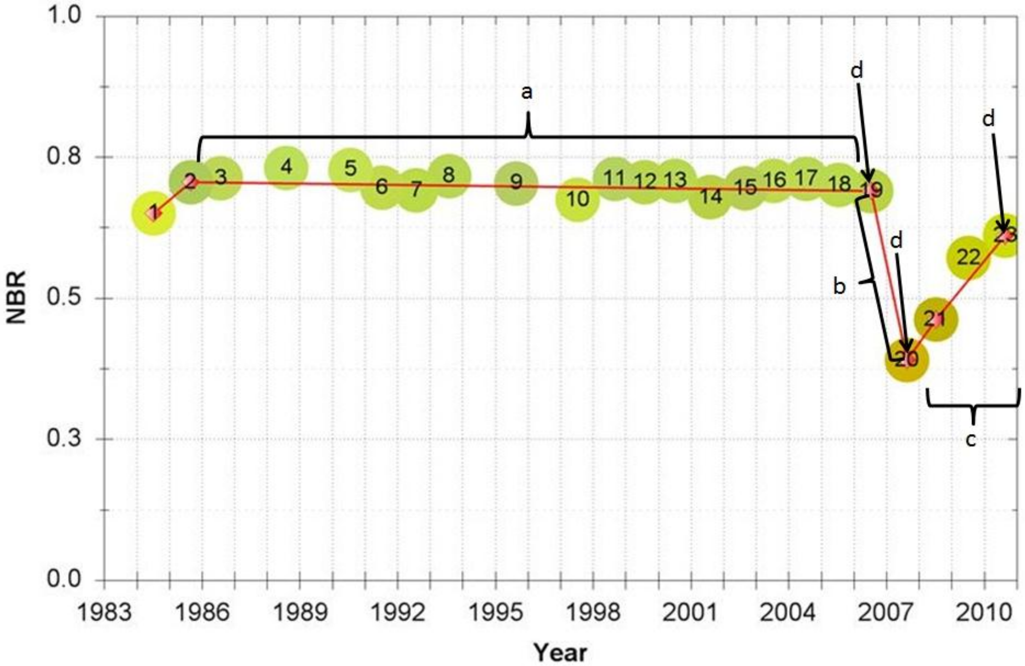

Figure 9. Diagram of how the LandTrendr segmentation algorithm processes a single pixel. The x-axis is the image year and the y-axis is the NBR value. Generally, NBR values correspond to the amount of vegetation present. This graph shows a single pixel's NBR value from 1984 to 2011. We would interpret this graph as: stable vegetation cover from 1985 to 2006 (a), with variation, or noise, each year, then a disturbance occurring in 2007 (b), causing a loss of vegetation, then recovering (c) to its original condition. This diagram also gives examples of vertices (d) connecting straight segments representing a smoothed pixel trajectory through time.

Validation of Disturbances

Validation of possible disturbances followed details given in Kirschbaum and Gafvert (2010), and is briefly summarized here. After disturbance polygons were created, the next step was to validate whether a change actually occurred in the polygon. In addition to validating whether changes occurred, additional information such as the pre- and post-disturbance vegetation classes (Table 3) and agent of change (Table 4) were identified during the validation process. Using high resolution imagery (Table 5), we were able to determine whether changes had indeed occurred, and by using contextual information (e.g., surrounding environment) we were able to determine the disturbance agent. In addition to using high resolution imagery, we also used an application called TimeSync (Cohen et al. 2010). This program allows the user to view composite image chips of the entire stack of Landsat imagery for pre-determined locations as well as the associated spectral trajectory of the pixel through time.

By viewing the high resolution aerial photos of the disturbance, its corresponding location on the series of Landsat image chips, and its spectral trajectory, we could make a well-informed decision regarding the validity and cause of change. If a disturbance occurred within a polygon, additional attributes (fields) were populated within the feature class (Table 6). These included most likely pre- and post-disturbance vegetation class, disturbance agent, post-timber harvest percent cover, and whether the polygon required a field visit for further verification. If a polygon spanned boundaries

(HUC 10, land owner, inside/outside park) we attributed the polygon with whatever the majority of the polygon represented.

Cross-validation of polygons

One interpreter validated all disturbances for INDU. However, in the future it is likely that more than one interpreter or different interpreters will validate disturbances. To assess the level of subjectivity and repeatability in the validation process, 10% of the polygons were randomly selected and evaluated by an independent interpreter. Complete results of this cross-validation process are presented in Appendix D.

Table 3. Land cover classes used in the analysis and their respective characteristics.

Vegetation class	Characteristics
Forest (closed)	>60% tree cover, >3m height
Forest (semi-closed)	30–60% tree cover, >3m height
Forest (open)	<30% tree cover, >3m height
Herbaceous/grassland	>60% cover of herbaceous species, <1m height
Water	Permanent (>10 years) bodies of water
Impervious surface	Black top, cement, or any surface water cannot easily penetrate.
Pervious surface	Barren land
Impervious/vegetated	Low and medium intensity developed areas which create a mosaic of impervious and vegetated surfaces, such as those regularly found in suburban areas.

Table 4. Disturbance agents and definitions.

Disturbance agent	Definition
Agriculture	Disturbance caused by human activity which results in agricultural land use (row crops, pasture, hay).
Beaver	When beavers flood a previously wooded wetland, it usually kills trees, which then show up as a disturbance.
Blowdown	The uprooting and tipping over of trees by wind. These blown down trees are evident in high resolution airphotos and are usually oriented in the direction of the wind event.
Development	Permanent conversion of vegetated surface to non-vegetated surface such as mines, paved roads, parking lots, and buildings.
Fire	Detection is limited to instances where there is mortality in the overstory. Thus, areas in which fires only burn the understory are not delineated.
Forest harvest	Forest harvests, including clearcuts and thinnings, new logging roads, and post-harvest prescriptions such as herbicide application or scarification.
Forest pathogen	Disturbances in the overstory due to insects (e.g., forest tent caterpillar, spruce budworm) or diseases (e.g., oak wilt).

Table 5. Aerial photos and high resolution satellite imagery used for validation. For explanation of acronyms used in this table, see List of Terms and Acronyms on page xiii.

Date	Resolution (meters)	Spectrum	Funding source	Type	Analysis area coverage
1998/2000	1	B&W	APFO-NAPP	Airphoto	Partial analysis area
Fall 2004	0.5	CIR	GLKN	Airphoto	INDU
Summer 2004	1	RGB	APFO-NAIP	Airphoto	Partial analysis area
Spring 2005	0.2	RGB	GLKN	Airphoto	INDU
Spring 2005	0.5 & 1	RGB	IndianaMap	Airphoto	Partial analysis area
Summer 2005	1	RGB	APFO-NAIP	Airphoto	Illinois portion
Summer 2006	1	RGB	APFO-NAIP	Airphoto	Entire
Summer 2007	1	RGB	APFO-NAIP	Airphoto	Indiana, Michigan portion
Summer 2008	1	RGB	APFO-NAIP	Airphoto	Lake County
Summer 2009	1	RGB	APFO-NAIP	Airphoto	Illinois, Michigan portion
Spring 2010	1	RGB	County	Airphoto	Porter County
Summer 2010	1	RGB	APFO-NAIP	Airphoto	Entire
Summer 2011	1	RGB	APFO-NAIP	Airphoto	Illinois portion
Summer 2012	1	RGB	APFO-NAIP	Airphoto	Indiana, Michigan portion
Summer 2012	1	RGB	APFO-NAIP	Airphoto	Entire
Summer 2012	1	RGB	APFO-NAIP	Airphoto	Entire
Spring 2013	0.15	4 band	GLKN, County	Airphoto	Indiana portion

Table 6. Attributes filled in during the validation process at each polygon.

Field	Definition
Location	INDU or Non-INDU
Start class	Starting vegetation class(es) as noted in Table 4. We indicate the three dominant (by area) vegetation classes present in the polygon.
Start class percent	Because the entire polygon is not always affected, this value is used to compute the actual area disturbed within the polygon.
End class	Ending vegetation class(es) present after the disturbance has occurred. These classes are determined using a decision tree described in Kirschbaum and Gafvert (2010).
End class percent	Same as start class percent, but for the ending vegetation class.
Disturbance agent	The interpreter uses all available contextual knowledge and available imagery to indicate disturbance agent(s) responsible for the change. For a list of possible agents, see Table 5.
Disturbance agent percent	The percent of the polygon disturbed by a particular agent.
Post-timber harvest remaining percent tree cover	The interpreter estimates the percent of tree cover remaining (±10%).
Land owner	The land owner data is from the GAP analysis program.
Field validation candidate	If the interpreter was not confident of the decision made by viewing available imagery and spectral trajectories, they would indicate that a field visit was necessary to confirm the polygon with a field visit.
Lab interpreter	Initials of interpreter who validated the polygon.

Results

Disturbance Agents and Percent of Land Disturbed

INDU

During the six-year study period, a total of 1.67% of the land area within the park administrative boundary was disturbed, (Figure 10). The majority of this total was 'Other', at 66% of all identified disturbances, though discussion with park staff revealed this was likely wetland restoration. Flooding accounted for 21% of disturbances, again likely wetland restoration. A small amount of forest harvest (11% of disturbances) was observed, discussion with the park revealed this was due to removal of black locust and other invasive species. No disturbances were identified in 2012.

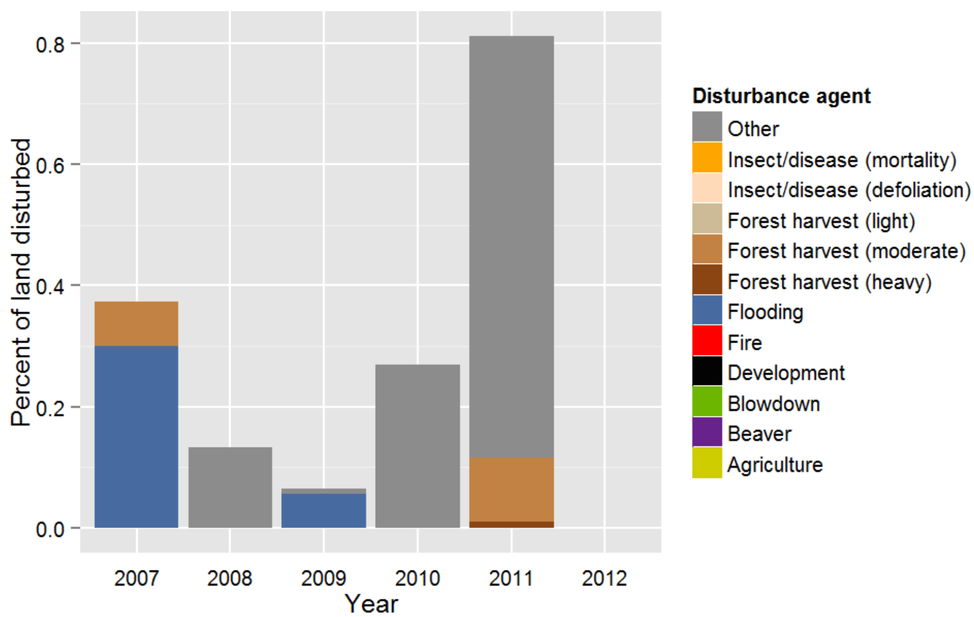

Figure 10. Percent of land disturbed inside the INDU administrative boundary, by causal agent and year.

Non-INDU

On lands outside the park boundary, development was by far the largest disturbance agent—83% of total disturbance area. On the other hand, the amount of land disturbed was very low—0.63% of the area over the six-year analysis period (Figure 10). The remaining disturbance agents were small areas of forest harvest (11% of disturbances), flooding (2.5%), conversions to agriculture (1.6%), and other/unknown (1.5%).

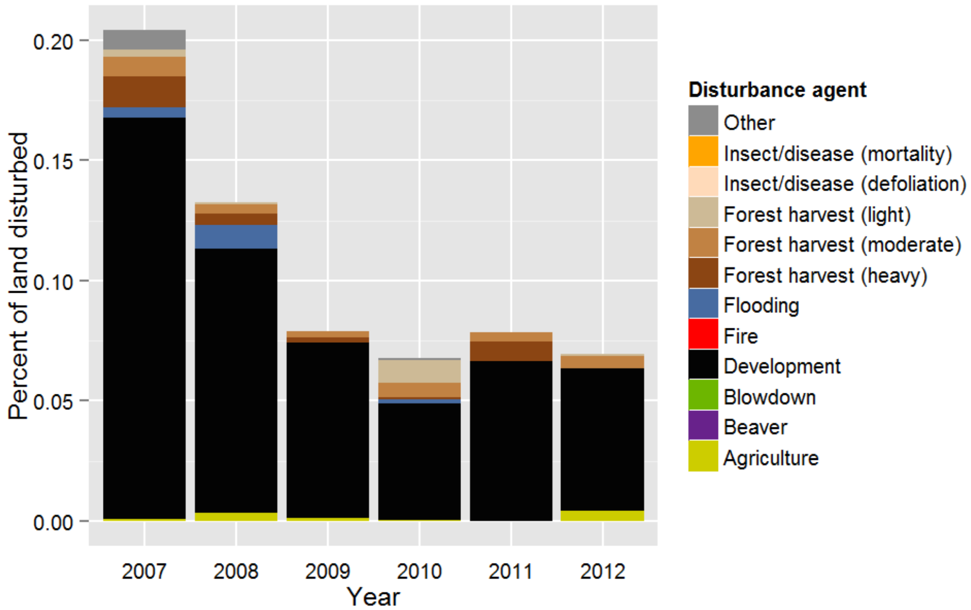

Figure 11. Percent of land disturbed outside INDU during the analysis period, by causal agent and year.

Land Cover Dynamics

During the validation process the interpreter can denote up to three separate pre- and post-disturbance vegetation classes for polygons that encompass multiple cover types. For more details on how pre- and post- vegetation disturbance classes are defined and chosen, see Kirschbaum and Gafvert (2010).

INDU

All disturbances that occurred on herbaceous cover remained herbaceous, being largely the result of wetland restoration (non-forested wetlands are included in our herbaceous land cover class). Most of the forest cover changes resulted in a change to a more open forest class. Closed forest converted to semi-closed, and semi-closed converted to open forest or herbaceous.

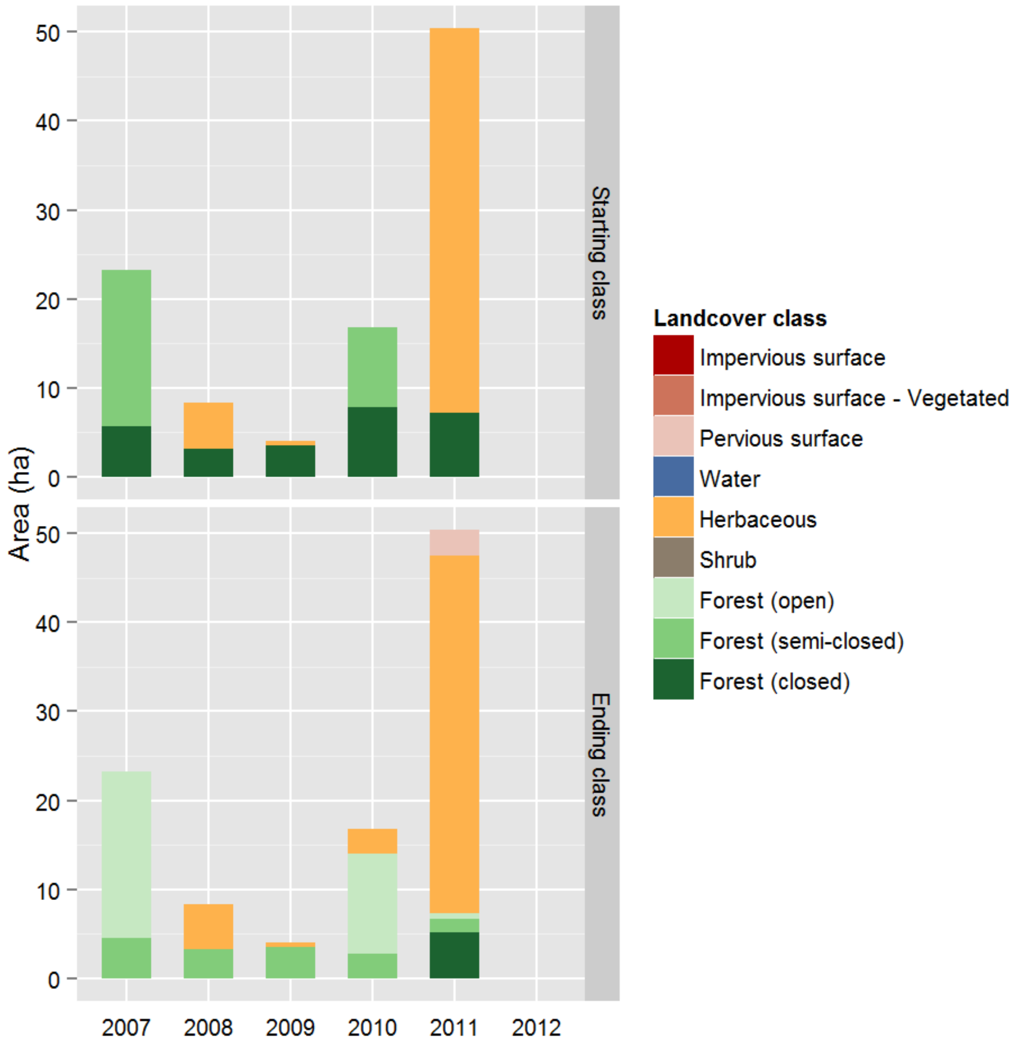

Figure 12. Area (in ha) of land cover type lost (starting class) and gained (ending class) at INDU during the analysis period (2007–2012). In some cases the cover type lost is the same as cover type gained. This occurs when a cover type has been affected, but the disturbance was not severe enough to alter the land cover class.

Non-INDU

The vast majority of land cover changes outside of the park boundary were due to a vegetated cover class (forest types, shrub or herbaceous) being converted to a developed class, with the majority of conversion to developed land in the impervious-vegetated class (Figure 12). This moderate density class is typically residential, such as cul-de-sacs, with multiple dwelling construction.

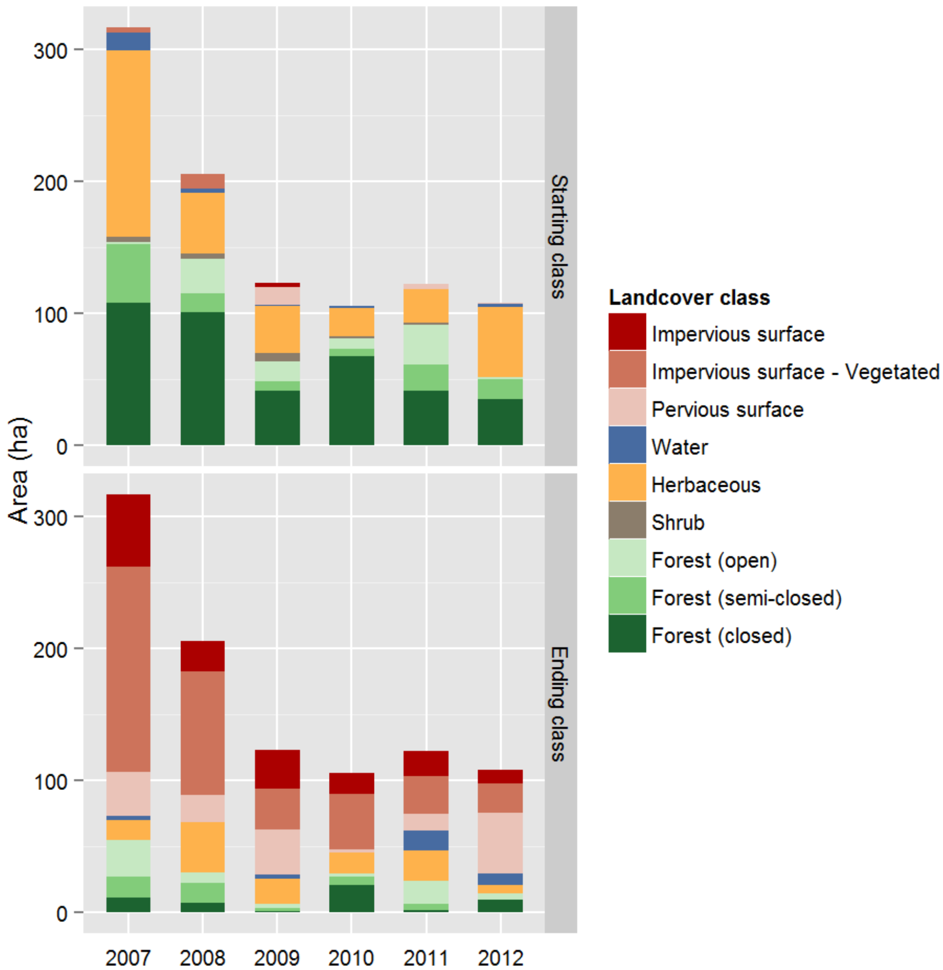

Figure 13. Area (in ha) of land cover type lost (starting class) and gained (ending class) outside the INDU administrative boundary during the analysis period (2007–2012).

Disturbance Agents by Watershed

The Calumet River Frontal Lake Michigan watershed had the highest percent of land disturbed during the analysis period, at nearly 1.6%. Just over half of the disturbances inside this watershed were due to development (54%), with another 40% attributed primarily to wetland restoration within INDU. The Salt Creek watershed had the next largest amount of disturbance, at 0.73%, with 93% of that being attributed to development. Development was by far the greatest disturbance agent in all other watersheds analyzed (Figure 14).

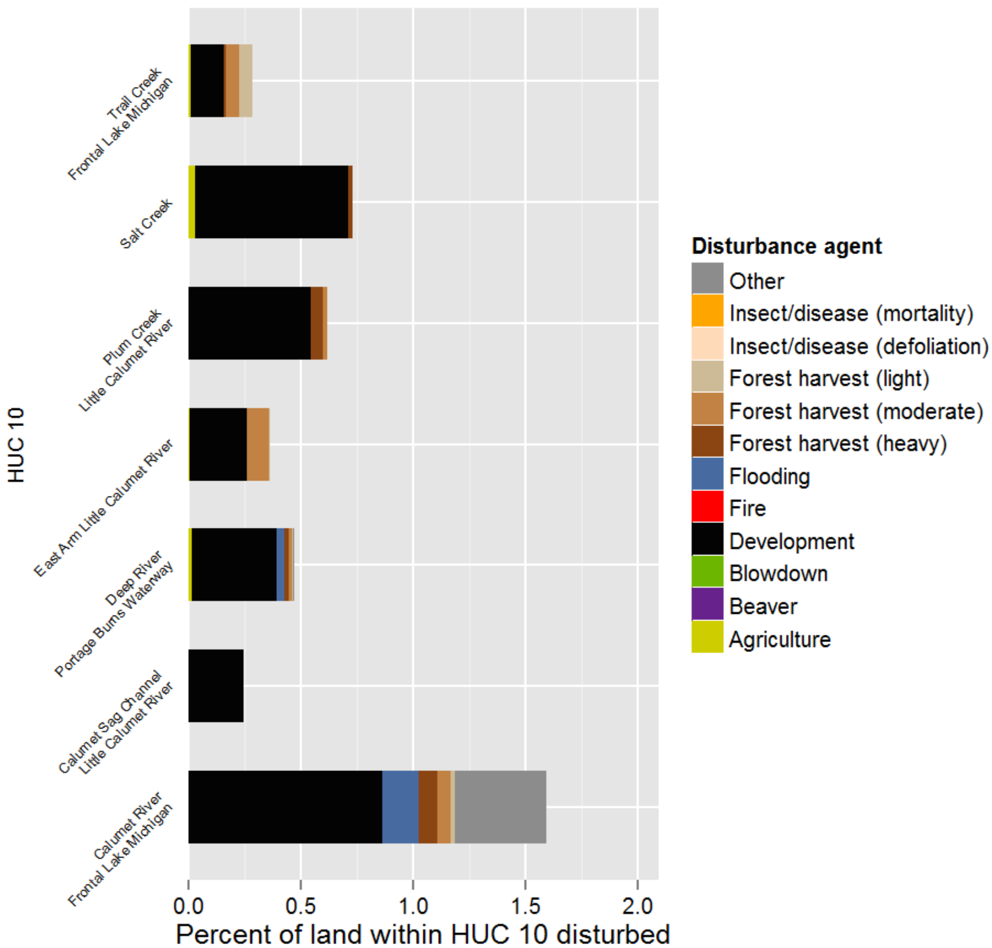

Figure 14. Percent of land disturbed within each watershed (HUC 10) by disturbance agent. For example, a total of 1.6% of the land within the Calumet River/Frontal Lake Michigan watershed was disturbed during the analysis time period.

Disturbance Agents by Ownership Type

For all other parks analyzed thus far, we have summarized disturbances based on land ownership patterns using the National Gap Analysis Program (GAP). Ownership information from the GAP within the INDU analysis area is only categorized to a few conservation status classes, and ‘unknown’. It is apparent that ‘unknown’ is private land, though there is no distinction between private commercial vs residential, or other distinctions. Private land comprises 93.8% of the analysis area, and 89% of all disturbances occurred on private land. By far the most dominant disturbance agent was development, accounting for 84% of all disturbances on private land. Land in various types of conservation status account for 6.2% of the total analysis area, with 11% of all disturbances occurring on these lands. The vast majority of that 11% occurred on NPS land, primarily the result of restoration efforts.

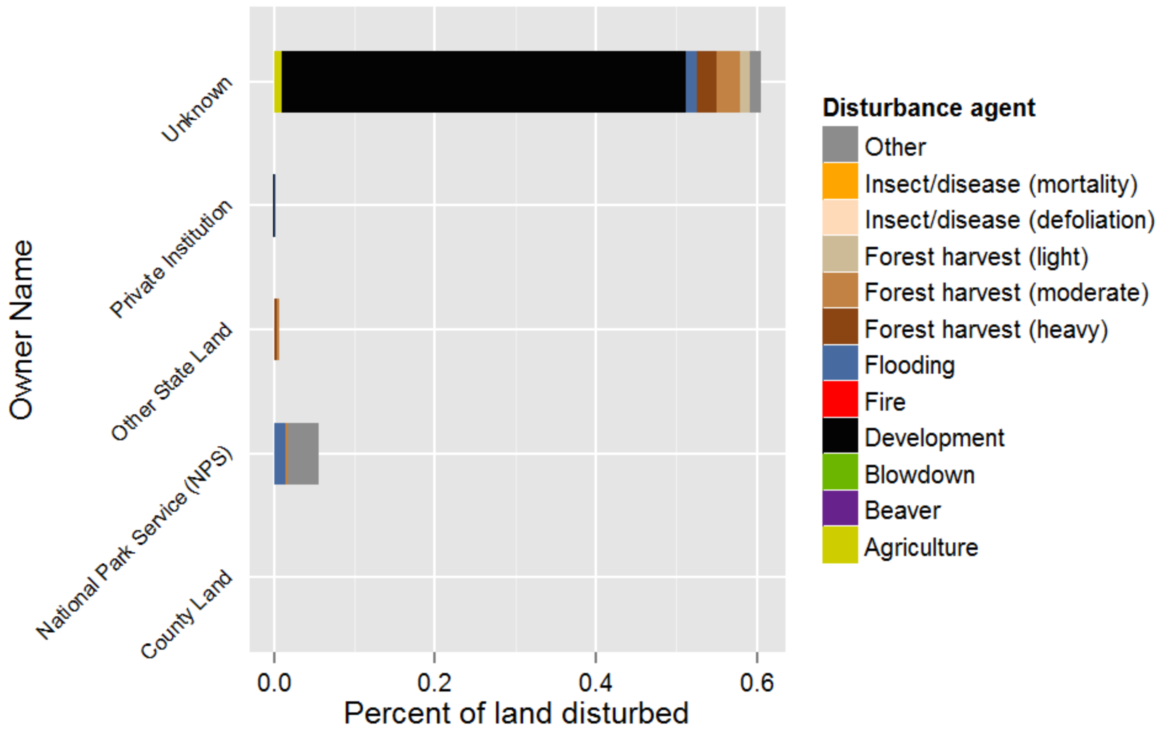

Figure 15. Percent of total land disturbed based on ownership type. 'Unknown' category is private land.

Discussion

The percent of land disturbed inside the park was almost three times more than outside the park over the time period analyzed. However, the types of disturbances inside the park are quite different than outside. Disturbances inside the park were labeled other/unknown during the validation phase, but discussion with park staff revealed the park was involved with several restoration projects. These include removal of invasive cattails in Cowles Bog (45 ha), restoring hydrologic regime in the Great Marsh (66 ha), and removal of black locust thickets (12.2 ha). Outside the park, the vast majority of disturbances were the result of development, such as new housing complexes, commercial/industrial construction, and road building.

This highlights the active management within the park boundary toward improving natural resources, and contrasts strongly with the continuing build-out of a largely urbanized landscape outside the park. Though development affected only a small portion of the area surrounding the park, at just over one half percent, such changes continue to consume the landscape. This increases impervious surface area, fragmentation, and loss of wildlife habitat. Another interesting note is the sharp decrease in development from 2009 through 2012. This pattern is very likely due to the 2009 market crash and overall economic slow-down.

Developed classes comprise almost 45% of the total area analyzed, according to the 2006 NLCD land cover dataset. Watersheds within the urban landscapes of Chicago and Gary are 60%–80% in developed classes. This continuing trend further isolates the park’s plant and animal communities, and compromises already challenged water quality and stream flow.

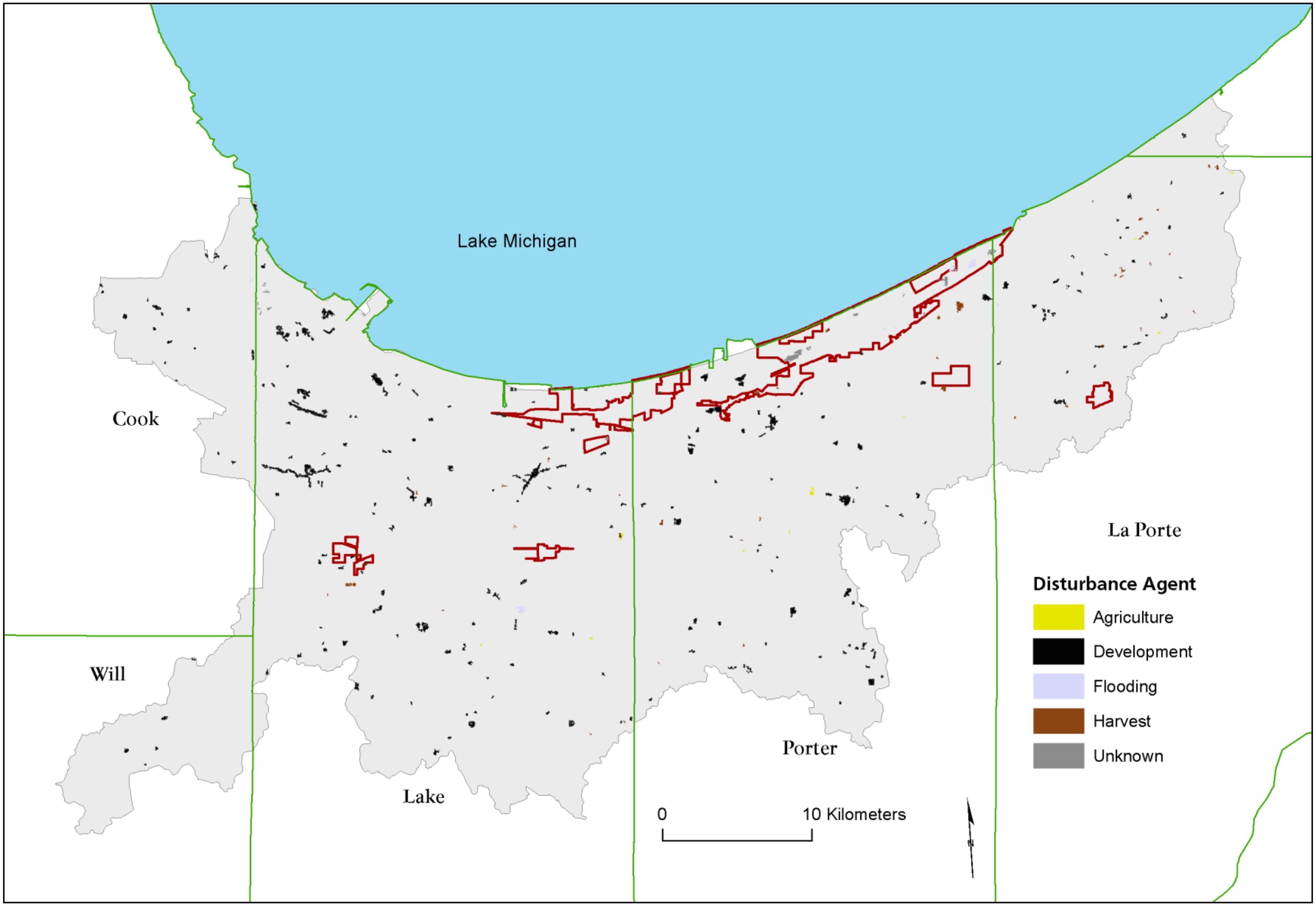

Figure 16. Spatial distribution of disturbances within the analysis area.

Indiana Dunes NL Compared to Other Great Lakes Network Parks

This is the eighth park in the Great Lakes Network we have analyzed for landscape-scale disturbance. The size and ecological boundaries of analysis areas differed among parks depending on whether a watershed or simple buffer approach seemed most appropriate. Simple distance buffers around parks were chosen at Voyageurs (VOYA), Isle Royale (ISRO), and Pictured Rocks (PIRO). For the remaining parks—Apostle Islands (APIS), Mississippi River (MISS), St. Croix River (SACN), Sleeping Bear Dunes (SLBE), and INDU—which are more affected by surface water flowing into the park, watershed boundaries were used to define analysis areas. Because this park is affected by upstream activities in these watersheds, the decision was made to choose the analysis area based upon watershed boundaries. Maps of the analysis areas for all parks can be found in Appendix F. Analysis areas (inside park plus outside park area) were all greater than 150,000 ha (Figure 17).

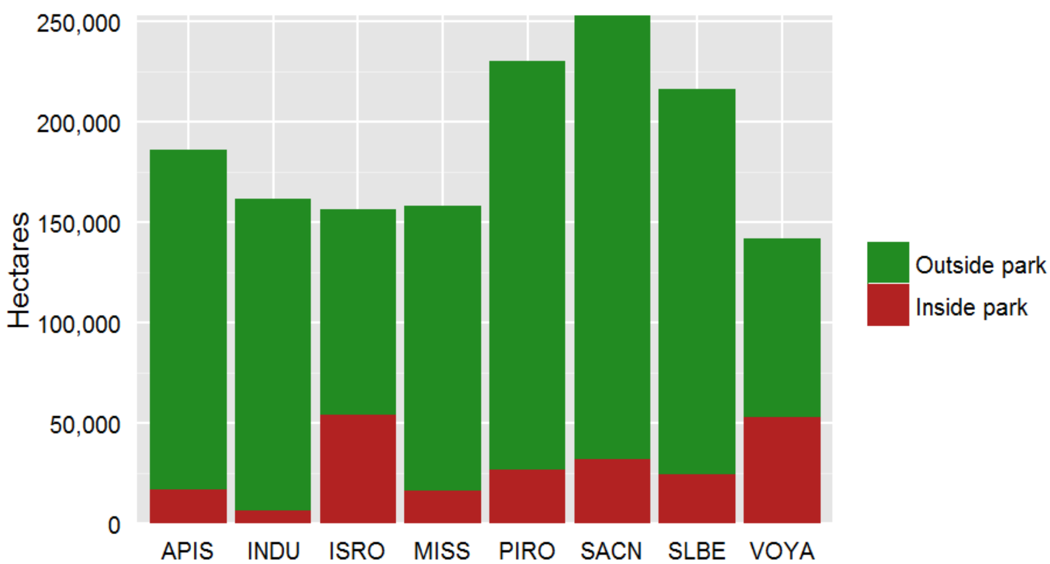

Figure 17. Land area monitored at each park in the Great Lakes Network. See List of Terms and Acronyms on pages xiii for key to park acronyms.

INDU is unique in having three times more disturbance (percent of area) inside the park compared with outside. Great Lakes Network parks span a gradient of population density from the urban landscapes of INDU and MISS to sparsely populated areas around VOYA and PIRO.

Examples of disturbance amounts in more rural settings include APIS (4%), PIRO (8.7%), and VOYA (6.3%) (Figure 18). Parks with low human density populations show that disturbances are dominated by resource extraction, largely forest harvest (Figure 19). These practices create an ever changing patchwork of young and older forest types, but forest continues to be the dominant land cover. Parks in and near urban centers see much smaller amounts of disturbance, INDU 0.63% and MISS, at 0.62%, but these disturbances are most commonly permanent changes on the landscape, resulting in slowly diminishing natural land cover (Figure 19).

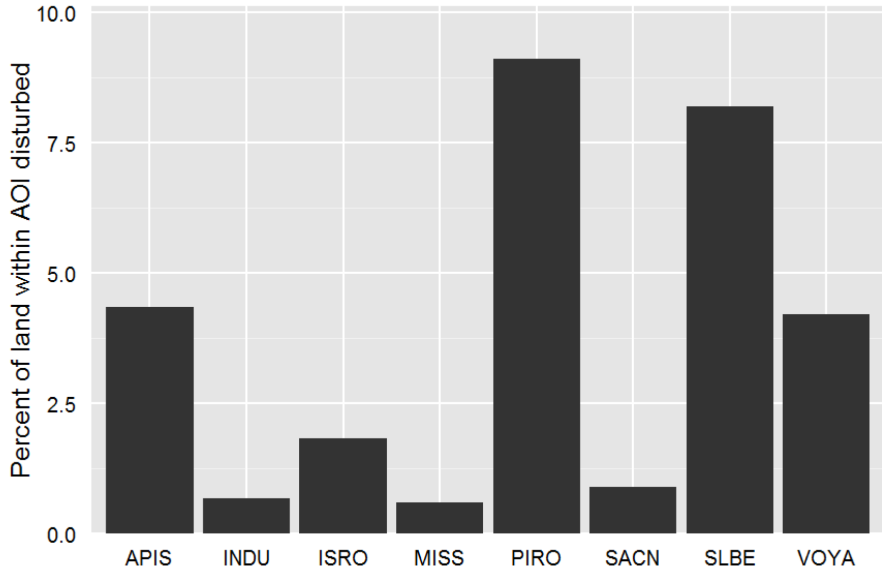

Figure 18. Percent of land disturbed within each analysis area (AOI, or area of interest). See List of Terms and Acronyms on pages xiii for key to park acronyms.

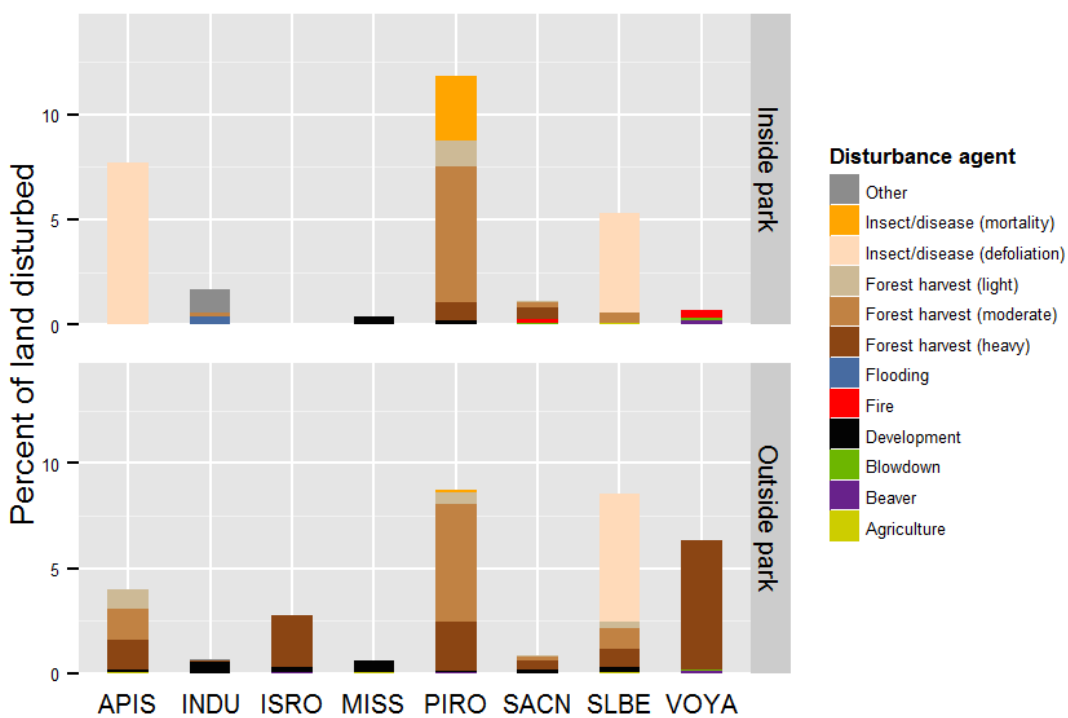

Figure 19. Percent of land disturbed inside the parks (top graph) and outside the parks (bottom graph) by causal agent. See List of Terms and Acronyms on pages xiii for key to park acronyms.

Conclusions

In this report we document six years of disturbance activity, providing a foundation for continued monitoring of the same types of activities and a long-term record of disturbance. This same analysis is scheduled to occur again in 2020. Future analyses may reveal trends in disturbance patterns or whole-scale changes in disturbance regime (size, location, frequency). For example, hypothesized effects of climate change such as increased high intensity storm events causing windthrow, or outbreaks of insect or disease due to higher mean annual temperatures, can be documented. Thus, over time, the relevance of information provided by this analysis will become increasingly valuable.

We have summarized the first period (2007–2012) of disturbance analysis at INDU into five points:

1) Among the eight parks analyzed, the INDU analysis area experienced the second lowest percent of disturbed lands. However, like disturbances at MISS, these were dominated by development, with increased impervious surface and fragmentation consequences.

2) Disturbances inside the park were almost exclusively due to natural resource restoration efforts.

3) Watersheds encompassing the urban areas of Chicago and Gary experienced the highest amounts of disturbance due to development. An exception to this is the Salt River watershed, which includes the community of Valparaiso, a town that experienced significant growth over the 6-year analysis period.

4) Agricultural lands, largely to the south and east of the park, are slowly being converted to developed land cover classes as communities such as Valparaiso continue to expand.

5) INDU exists in a landscape almost entirely modified for human uses. Thus the park is an isolated remnant of a formerly vast and rich ecosystem. Maintaining species diversity and viability will likely become increasingly challenging in the future.

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Appendix A. Spatial Distribution of Disturbances Inside INDU.

This appendix documents the spatial distribution of disturbances within the park boundary. Distribution maps are followed by snapshots of before and after aerial photography highlighting disturbances of particular interest. These include a number of apparent forest and wetland restoration projects. Several are classed as 'Other' during validation, but discussion with park staff revealed the cause of the disturbance captured by LandTrendr.

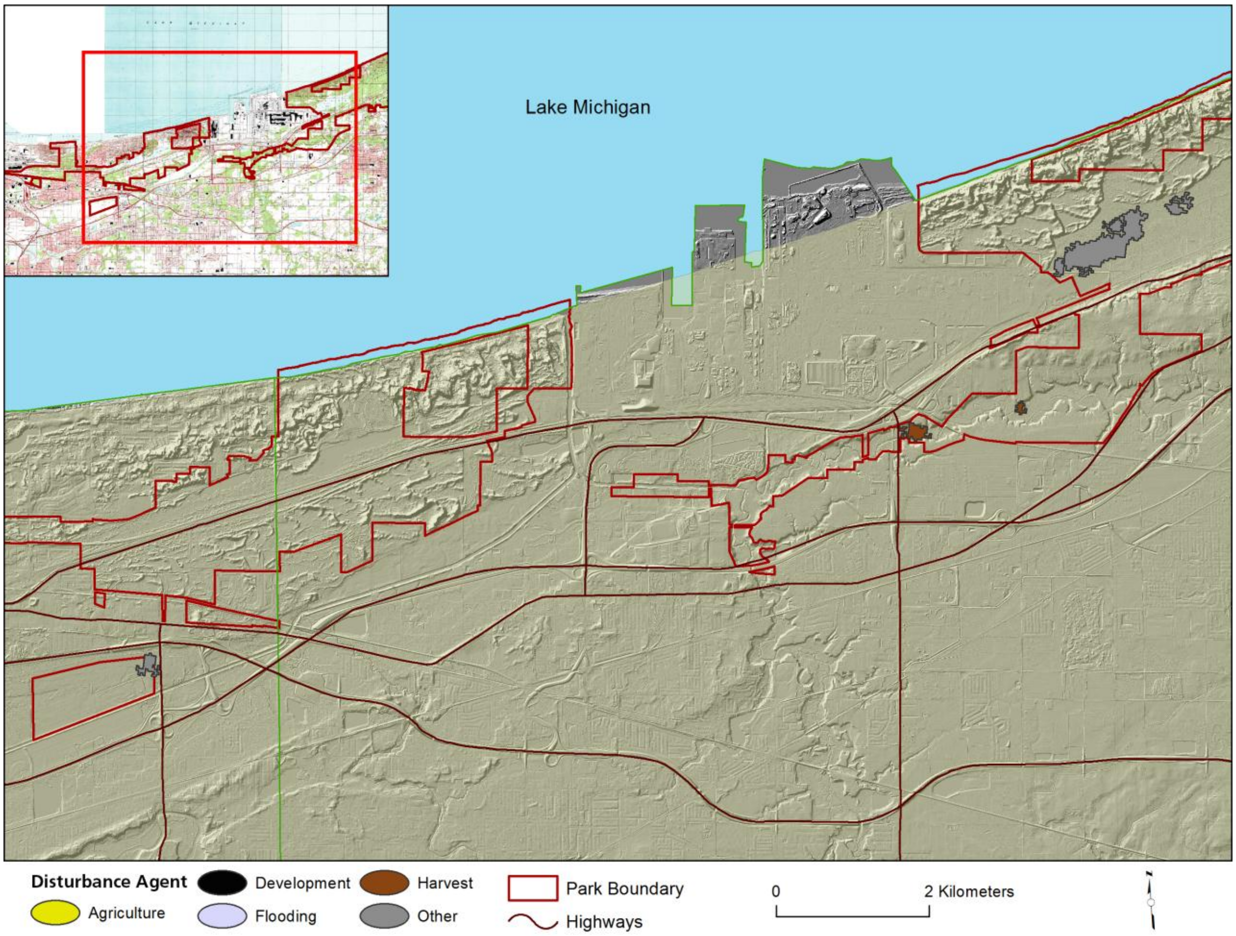

Figure A1. Close-up of disturbances inside INDU (west half) during the analysis period.

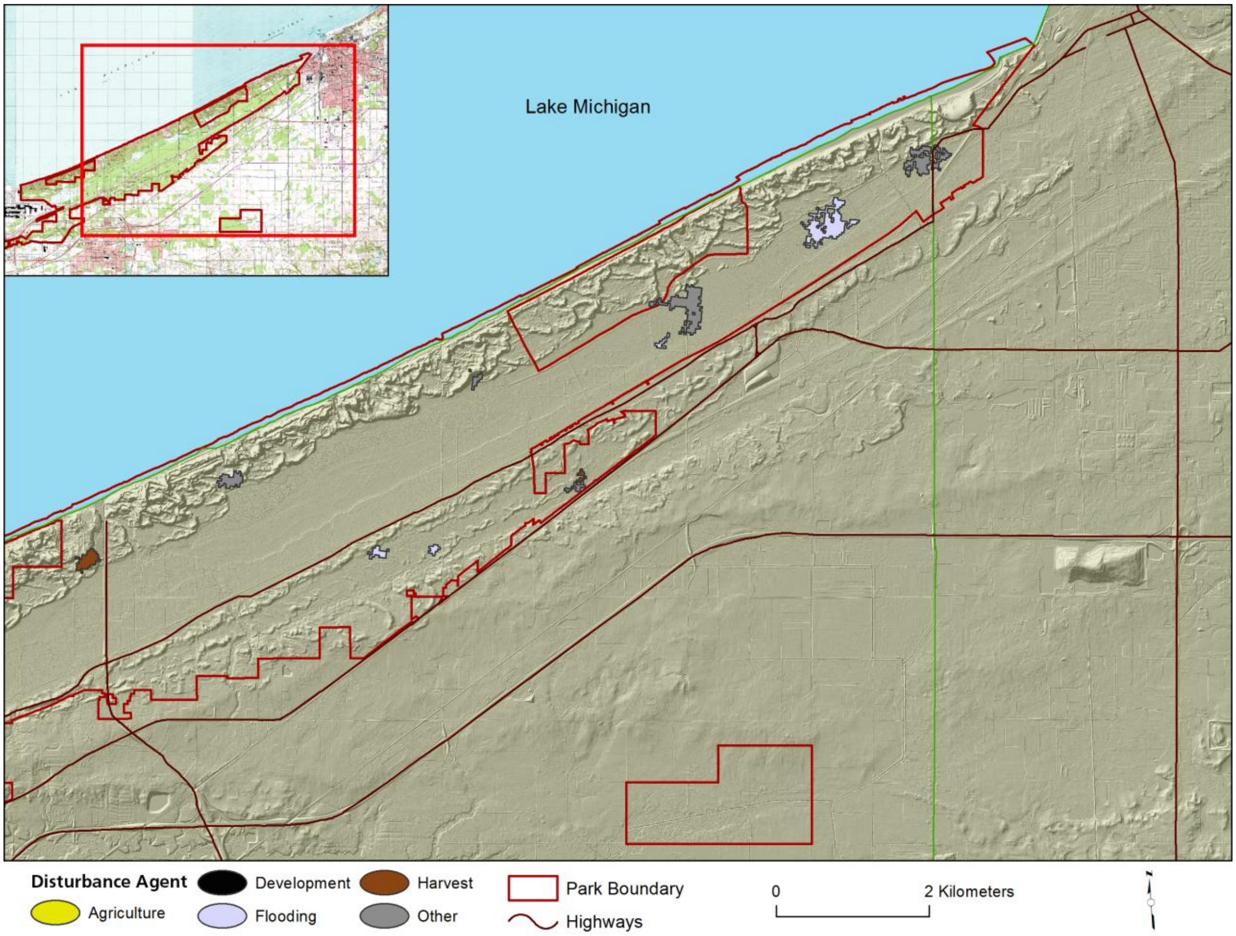

Figure A2. Close-up of disturbances inside INDU (east half) during the analysis period.

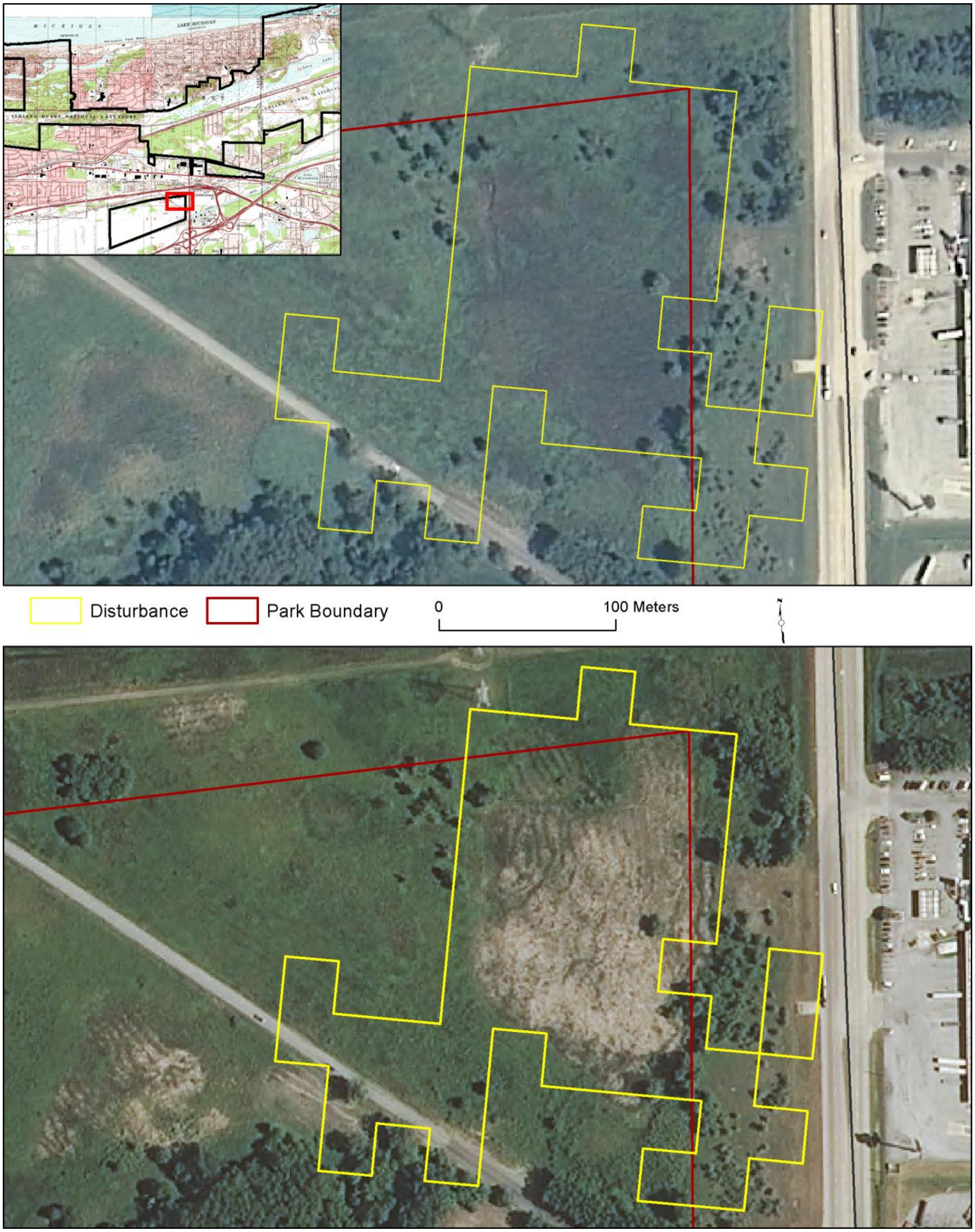

Figure A3. Wetland restoration efforts at Calumet Prairie. Air photo on top is from 2010, bottom photo from 2012.

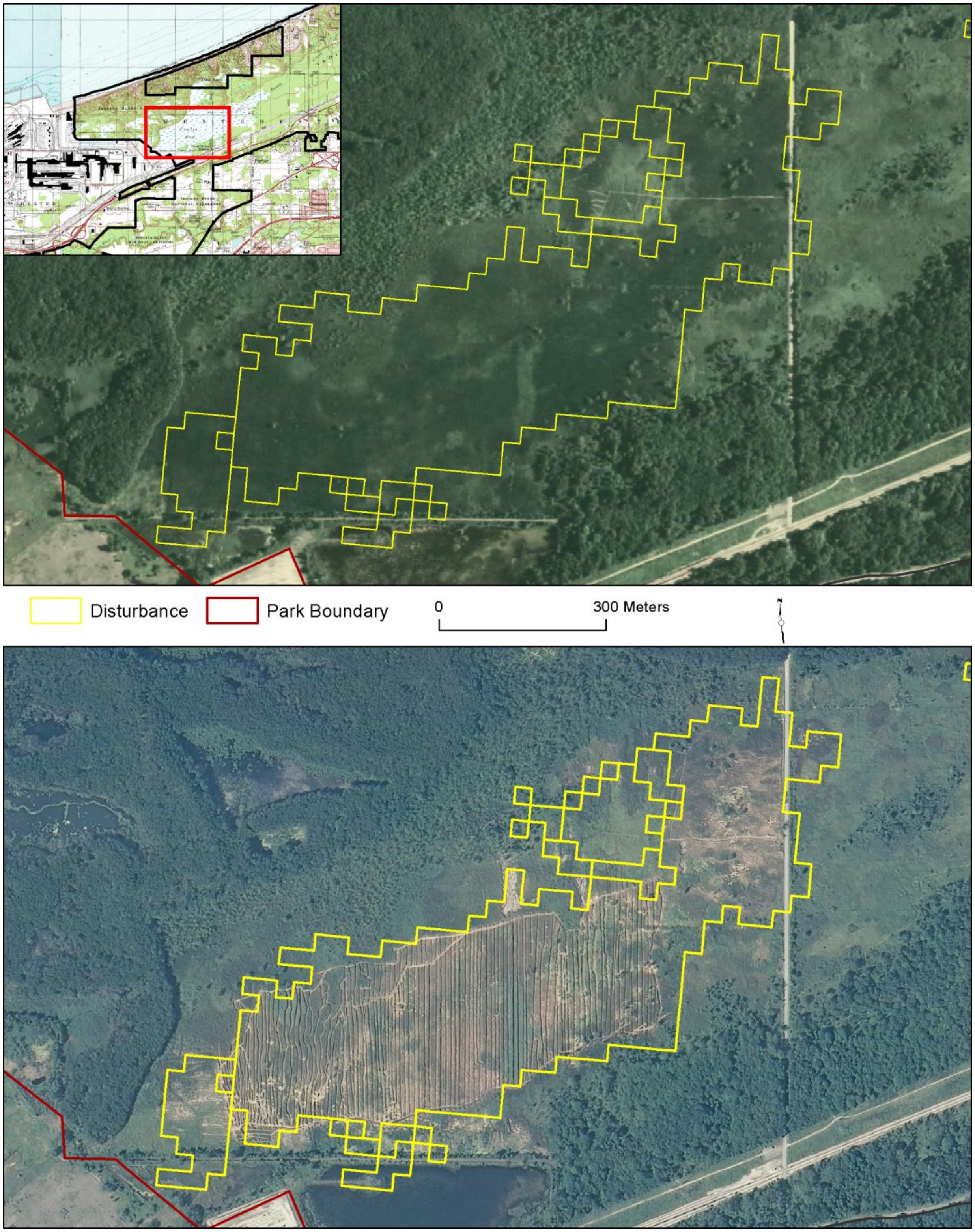

Figure A4. Removal of invasive cattails in Cowles Bog. Air photo on top is from 2007, bottom image from 2010.

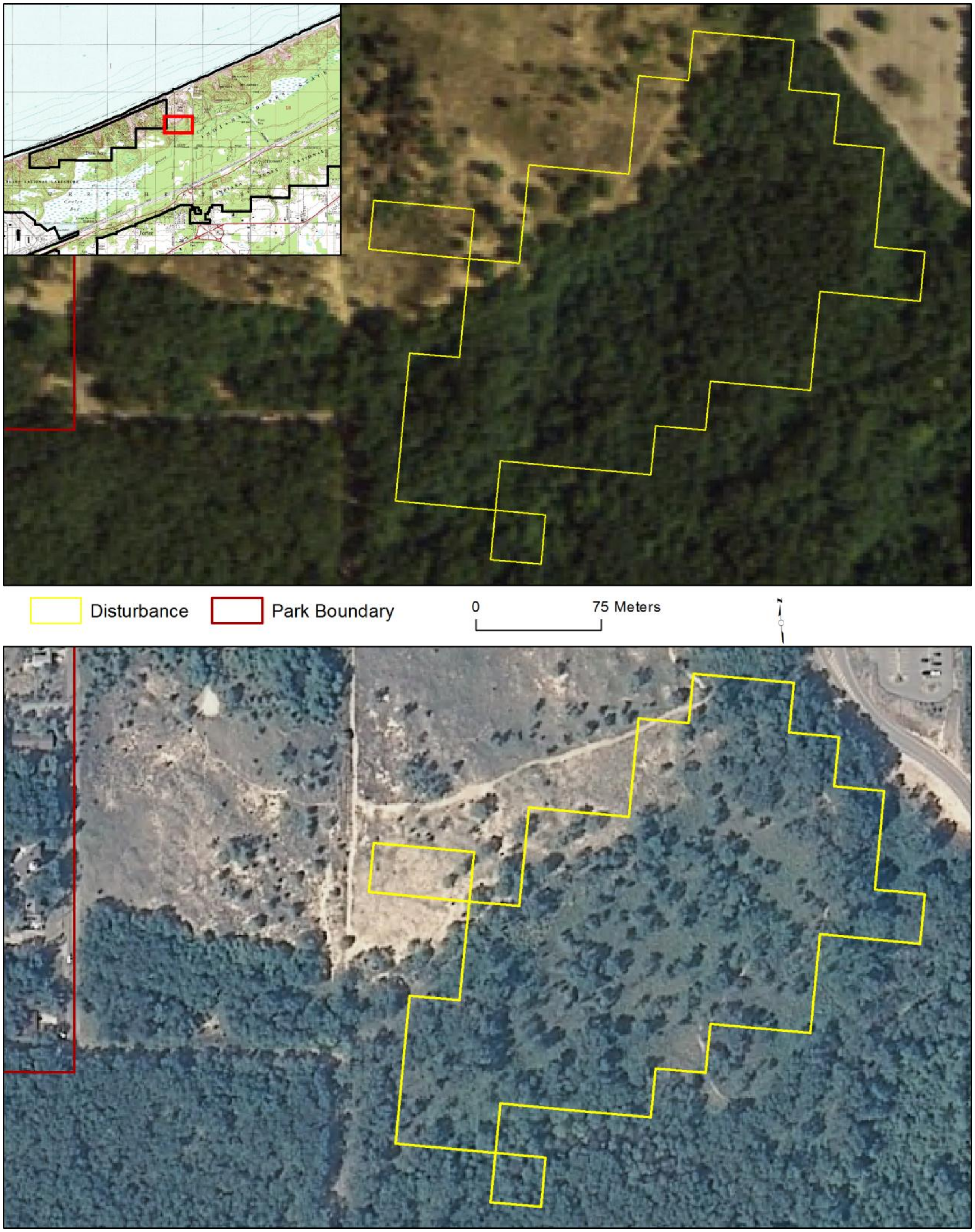

Figure A5. Disturbance due to forest harvest that occurred in 2007. Top shows 2006 airphoto, bottom shows 2010 airphoto.

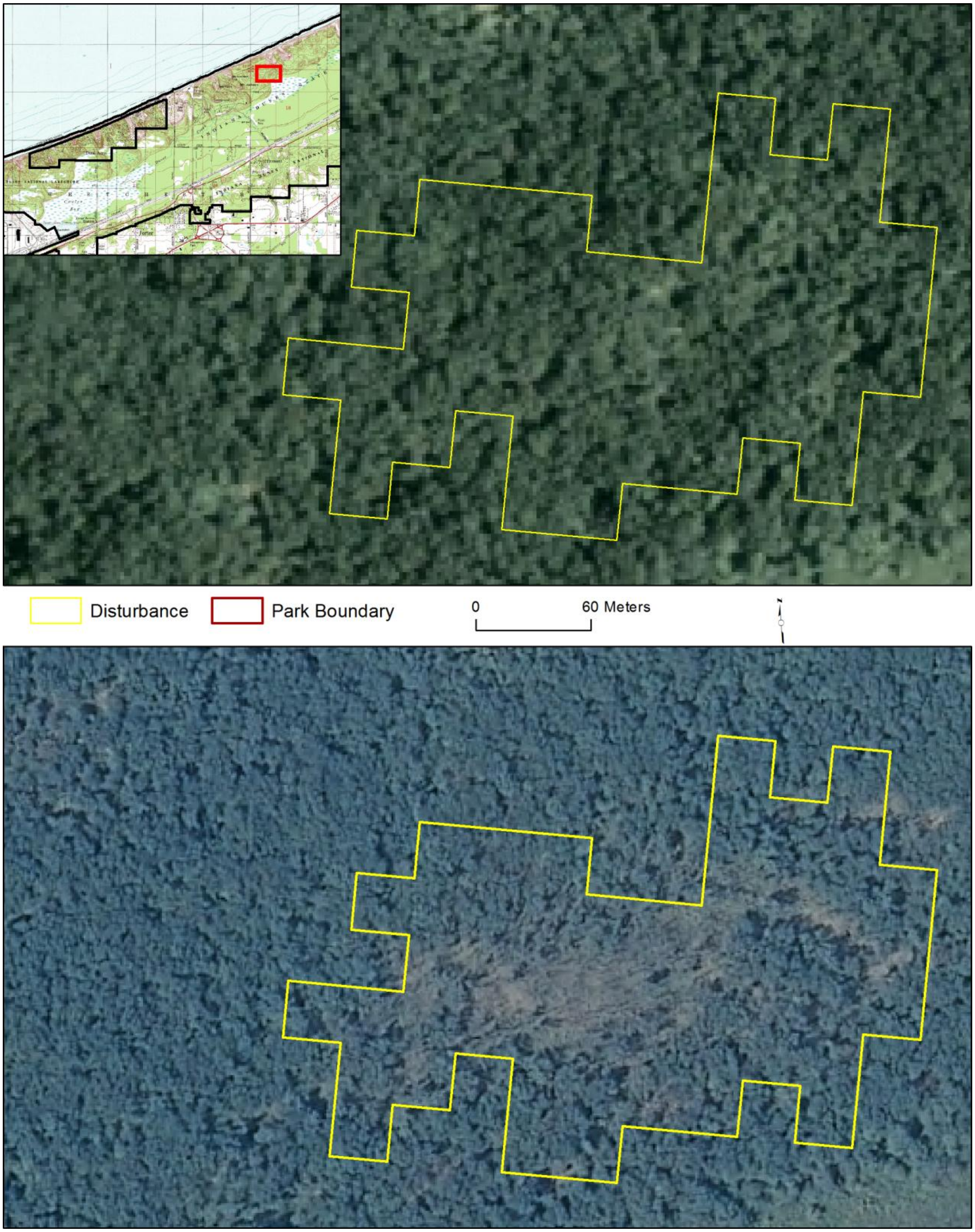

Figure A6. Unknown disturbance, either partial forest harvest or possible mortality from forest pathogen that occurred in 2008. Top shows 2007 airphoto, bottom shows 2010 airphoto.

Appendix B. Spatial Distribution of Disturbances Outside INDU.

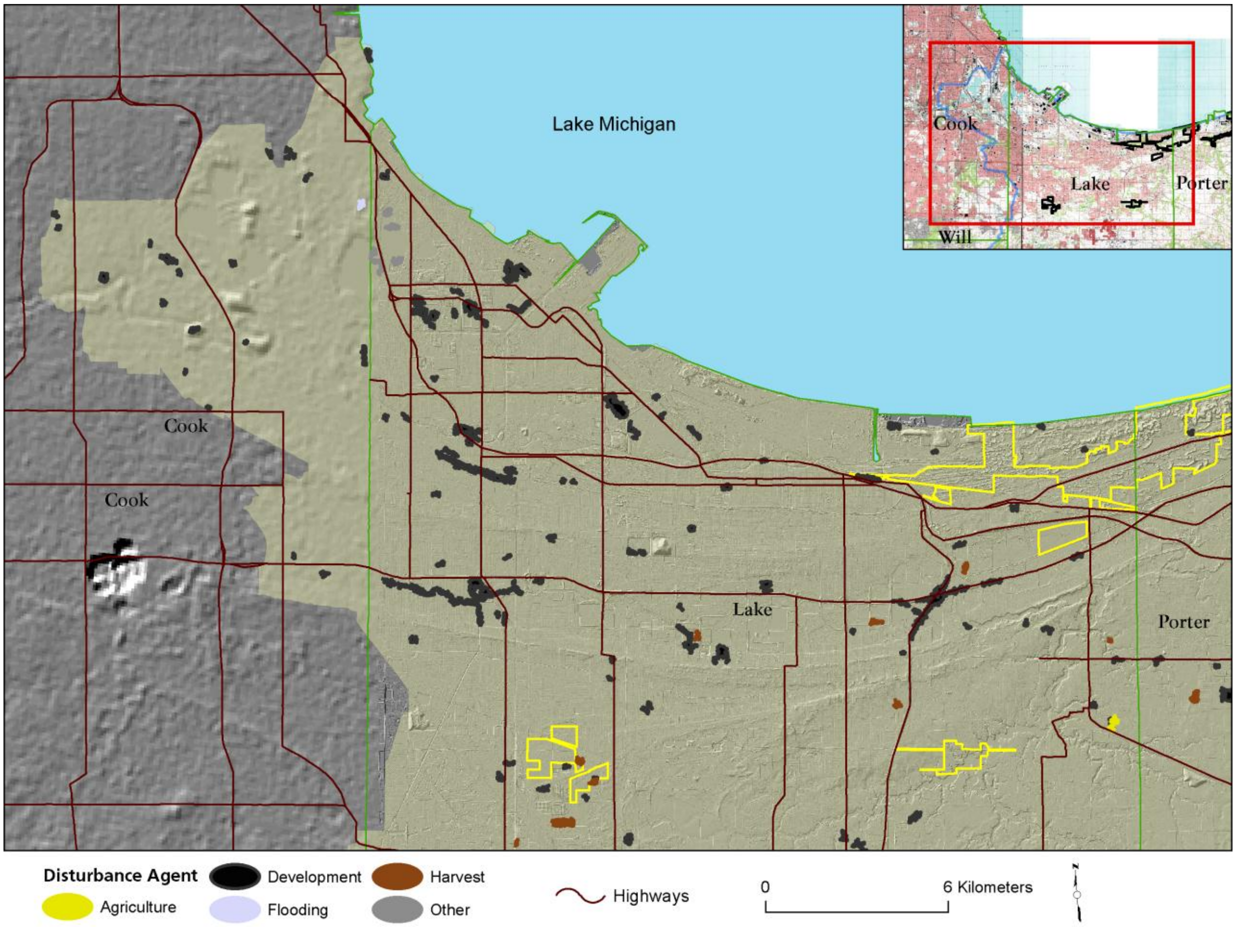

Figure B1. Overview of disturbances outside INDU during the analysis period. This map shows the northwest quarter of the analysis area.

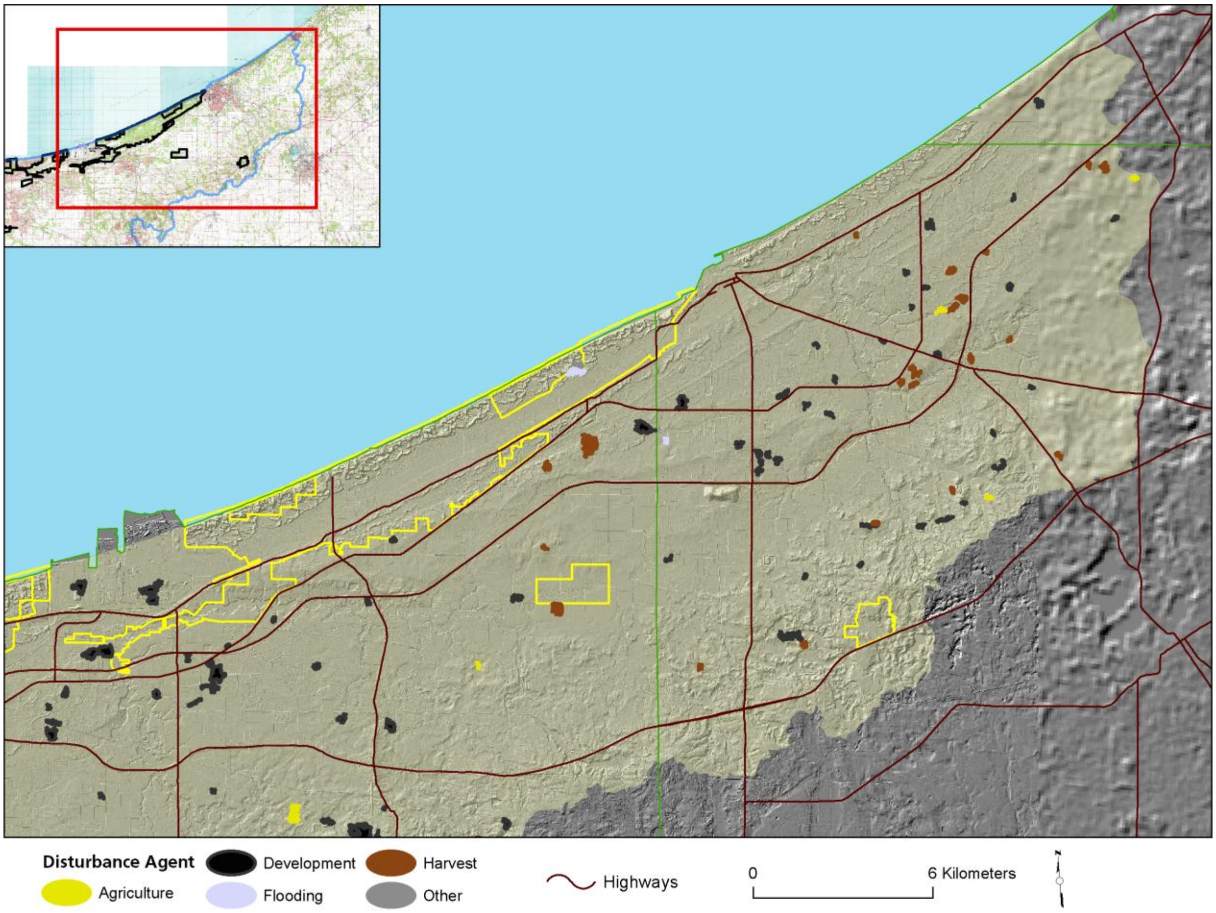

Figure B2. Overview of disturbances outside INDU during the analysis period. This map shows the northeast quarter of the analysis area.

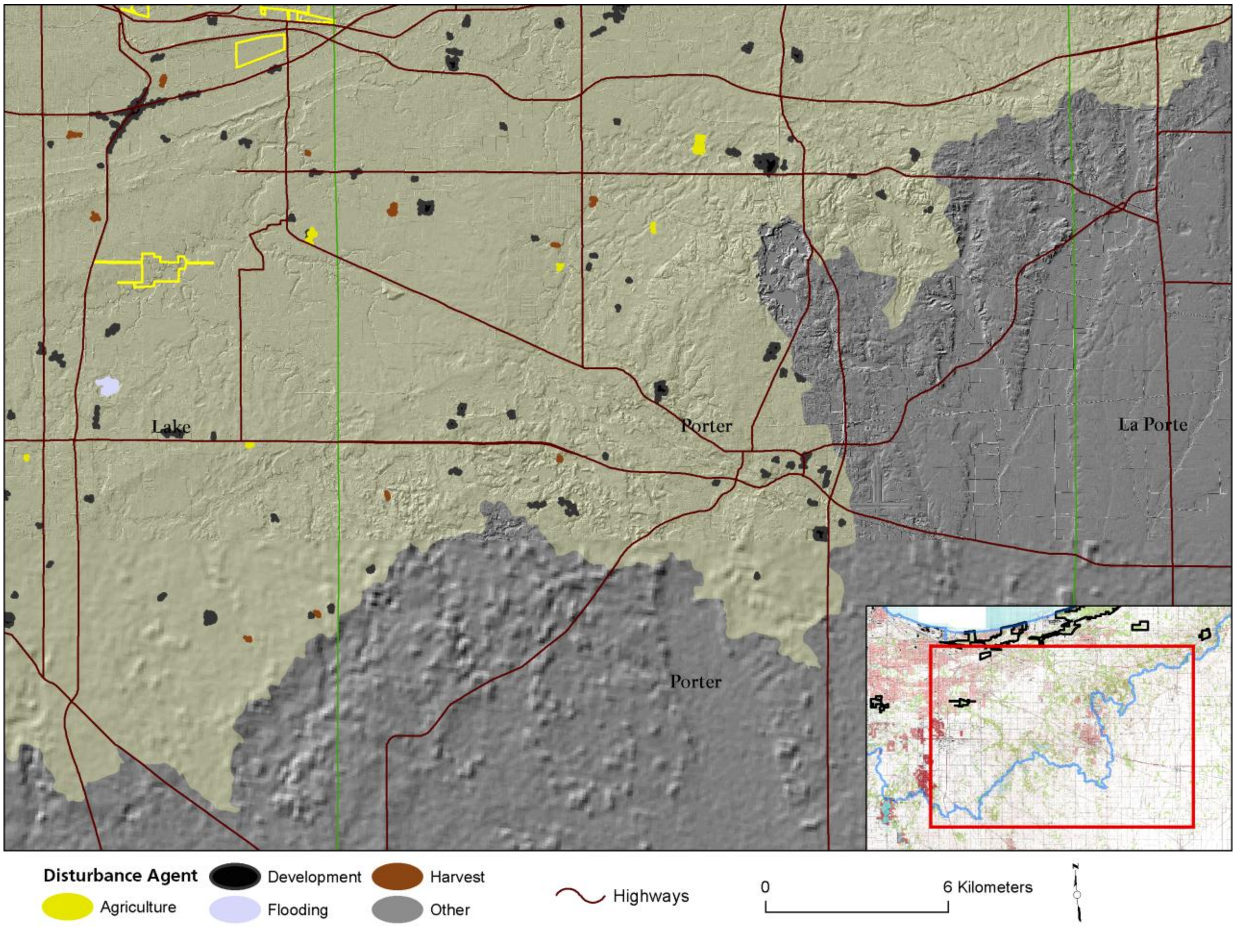

Figure B3. Overview of disturbances outside INDU during the analysis period. This map shows the southeast quarter of the analysis area.

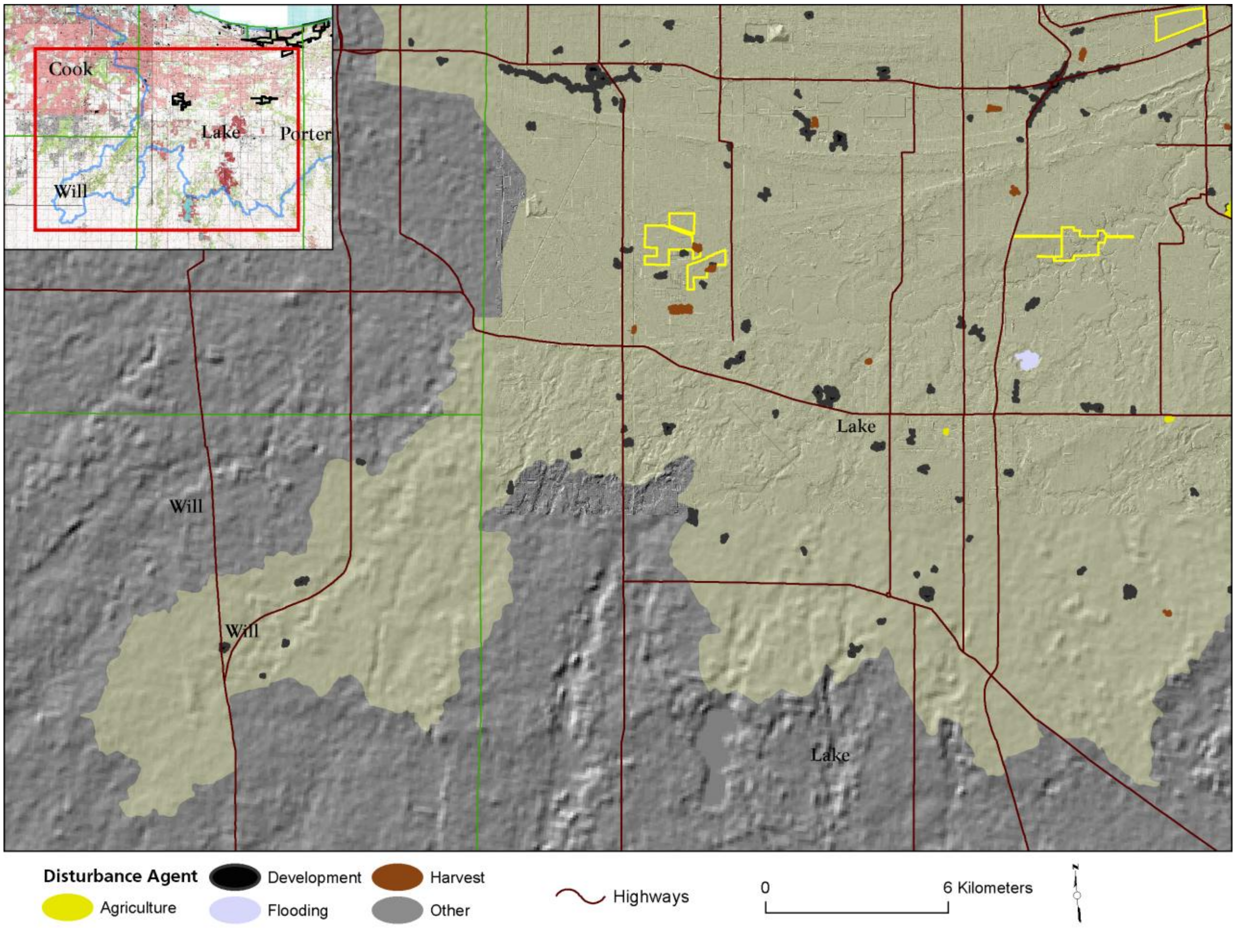

Figure B4. Overview of disturbances outside INDU during the analysis period. This map shows the southwest quarter of the analysis area.

Appendix C. Supplemental Tables.

Table C1. Area (ha) and percent of each land cover class within the analysis area. Data summarized from the 2006 NLCD.

Class name	Percent of analysis area	Area (ha)
Open water	1.65	2712
Developed, open space	8.94	14666
Developed, low intensity	20.51	33636
Developed, medium intensity	10.02	16433
Developed, high intensity	5.40	8859
Barren land	0.31	513
Deciduous forest	12.82	21030
Evergreen forest	0.25	415
Mixed forest	0.30	490
Shrub	3.60	5902
Grassland/herbaceous	6.17	10121
Pasture	4.47	7334
Cultivated crops	15.66	25690
Woody wetlands	9.12	14966
Emergent herbaceous wetlands	0.76	1246

Table C2. Percent of location and area (ha) of land disturbed by year and analysis area.

Year	INDU (ha)	INDU (%)	Non-INDU (ha)	Non-INDU (%)
2007	23.22	0.37	316.67	0.20
2008	8.31	0.13	205.61	0.13
2009	4.01	0.06	122.80	0.08
2010	16.74	0.27	105.47	0.07
2011	50.36	0.81	122.09	0.08
2012	0	0	108.07	0.07
Total	**102.64**	**1.64**	**980.71**	**0.63**

Table C3. Hectares disturbed by disturbance agent, year, and analysis area.

Analysis area	Year	Area of land disturbed (ha) by disturbance agent							
		Agriculture	*Development*	*Flooding*	*Forest harvest (light)*	*Forest harvest (moderate)*	*Forest harvest (heavy)*	*Unknown/Other*	**Total**
INDU	2007	0	0	18.68	0	4.54	0	0	**23.22**
	2008	0	0	0	0	0	0	8.31	**8.31**
	2009	0	0	3.51	0	0	0	0.5	**4.01**
	2010	0	0	0	0	0	0	16.74	**16.74**
	2011	0	0	0	0.59	6.66	0	43.11	**50.36**
	2012	0	0	0	0	0	0	0	**0**
	Total	**0**	**0**	**22.19**	**0**	**11.2**	**0**	**68.66**	**102.64**
Non-INDU	2007	1.53	258.54	7.06	20	12.54	4.18	12.82	**316.67**
	2008	5.17	170.82	15.23	7.2	6.02	1.17	0	**205.61**
	2009	2.03	113.43	0	3.02	4.31	0	0	**122.79**
	2010	0.54	75.52	2.43	1.13	9.36	14.69	1.8	**105.47**
	2011	0	102.85	0	13.28	5.96	0	0	**122.09**
	2012	6.4	91.81	0	0.4	8.21	1.26	0	**108.08**
	Total	**15.67**	**812.97**	**24.72**	**45.03**	**46.4**	**21.3**	**14.62**	**980.71**

Table C4. Percent of land disturbed inside each location (INDU, Non-INDU) by disturbance agent, year, and analysis area.

		Percent of land disturbed by disturbance agent							
Analysis area	**Year**	*Agriculture*	*Development*	*Flooding*	*Forest harvest (light)*	*Forest harvest (moderate)*	*Forest harvest (heavy)*	*Unknown/Other*	**Total**
INDU	2007	0	0	0.3	0	0.07	0	0	**0.37**
	2008	0	0	0	0	0	0	0.13	**0.13**
	2009	0	0	0.06	0	0	0	<0.01	**0.06**
	2010	0	0	0	0	0	0	0.27	**0.27**
	2011	0	0	0	<0.01	0.11	0	0.69	**0.8**
	2012	0	0	0	0	0	0	0	**0**
	Total	**0**	**0**	**0.36**	**0**	**0.18**	**0**	**1.09**	**1.63**
Non-INDU	2007	<0.01	0.17	<0.01	0.01	<0.01	<0.01	<0.01	**0.17**
	2008	<0.01	0.11	<0.01	<0.01	<0.01	<0.01	0	**0.13**
	2009	<0.01	0.07	0	<0.01	<0.01	0	0	**0.08**
	2010	<0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	**0.07**
	2011	0	0.07	0	<0.01	<0.01	0	0	**0.08**
	2012	<0.01	0.06	0	<0.01	<0.01	<0.01	0	**0.07**
	Total	**<0.01**	**0.53**	**<0.01**	**0.01**	**<0.01**	**<0.01**	**0**	**0.6**

Table C5. Summary of the starting classes from the validated disturbance polygons. In some instances the starting class is the same as the ending class because not enough of the overstory was removed.

		Area (ha) of land cover types disturbed in the analysis period (starting class)								
Analysis area	**Year**	*Forest (closed)*	*Forest (semi-closed)*	*Forest (open)*	*Shrub*	*Herbaceous*	*Water*	*Pervious surface*	*Impervious surface*	*Impervious/ vegetated*
INDU	2007	5.67	17.55	0	0	0	0	0	0	0
	2008	3.21	0	0	0	5.09	0	0	0	0
	2009	3.51	0	0	0	0.5	0	0	0	0
	2010	7.83	8.91	0	0	0	0	0	0	0
	2011	7.25	0	0	0	43.11	0	0	0	0
	2012	0	0	0	0	0	0	0	0	0
	Total	**27.44**	**26.46**	**0**		**48.71**	**0**	**0**	**0**	**0**
Non-INDU	2007	107.92	44.21	1.76	4.57	141.44	12.82	0	0	3.96
	2008	100.74	14.12	26.59	3.99	45.79	3.24	0.35	0	10.79
	2009	41.42	7.11	14.74	6.78	35.77	0.76	13.26	2.96	0
	2010	67.87	5.42	7.6	1.48	21.48	1.62	0	0	0
	2011	41.28	19.73	30.72	1.58	25.24	0	3.54	0	0
	2012	34.54	15.33	1.64	0	53.13	2.83	0	0	0
	Total	**393.77**	**105.91**	**83.05**	**18.41**	**322.85**	**21.26**	**17.74**	**2.96**	**14.74**

Table C6. Summary of the ending classes from the validated disturbance polygons.

Analysis area	Year	Area (ha) of land cover types disturbed in the analysis period (ending class)							
		Forest (closed)	*Forest (semi-closed)*	*Forest (open)*	*Herbaceous*	*Water*	*Impervious surface*	*Pervious surface*	*Impervious/ vegetated*
INDU	2006	332.91	0	1.08	4.86	0	0	0	0
	2007	0	0	2	0	1.46	0	0	0
	2008	2.73	0.78	1.17	0	0	0	0	0.25
	2009	725.58	0	0	0	0	0	0	0
	2010	208.08	0	0	0	0	0	0	0
	2011	0	0	1.17	4.87	0	0	0	0
	Total	**1269.3**	**0.78**	**5.41**	**9.73**	**1.46**	**0**	**0**	**0.25**
Non-INDU	2006	490.59	40.99	376.86	69.48	0	5.24	9.2	121.26
	2007	460.42	110.41	284.19	58.49	0.39	0	17.01	56.87
	2008	513.47	96.39	272.09	24.08	0	6.61	4.13	16.12
	2009	10930.83	330.87	369.3	20.58	0	8.45	5.6	16.01
	2010	1048.27	44.63	168.79	49.22	0.61	0	2.85	8.5
	2011	16.47	20.41	214.16	9.94	0.32	0	0	8.1
	Total	**13460.05**	**643.7**	**1685.38**	**231.79**	**1.32**	**20.29**	**38.79**	**226.86**

Table C7. Area (ha) of land disturbed inside the analysis area by HUC 10.

HUC 10	Agriculture	Development	Flooding	Forest harvest (light)	Forest harvest (moderate)	Forest harvest (heavy)	Unknown/Other
Calumet River-Frontal Lake Michigan	0	167.11	31.69	16.41	11.31	3.51	79.23
Calumet Sag Channel-Little Calumet River	0	115.25	0	0	0	0	0
Deep River-Portage Burns Waterway	5.76	176.02	15.23	8.58	7.02	1.17	4.05
East Arm Little Calumet River	0.54	48.47	0	0.00	18.92	1.26	0
Plum Creek-Little Calumet River	0	132.53	0	14.18	4.70	0	0
Salt Creek	6.318	135.16	0	3.55	0	0	0
Trail Creek-Frontal Lake Michigan	3.051	38.43	0	2.92	15.64	15.36	0

Table C8. Percent of land by owner within the INDU analysis area.

Owner	Percent
National Lakeshore	2.6
State of Indiana	1.5
Local Government	0.11
Non-Governmental Organization	0.1
Private	95.6

Appendix D. Results From Interpreter Cross-Validation.

We make every effort to reduce the amount of user bias that could be introduced into the validation process. We measured observer bias by randomly selecting 10% of each validator's polygons and having the other interpreter independently assess each one. This appendix provides the summary results from this cross-validation exercise.

The first decision an interpreter needs to make is whether the polygon is a true disturbance or has been falsely identified by LandTrendr. There were 252 polygons (10%) randomly selected for cross validation and of those polygons, the interpreters agreed on 230, or 91%. The majority (90%) of the agreement was due to the 206 polygons both interpreters determined were false. This is excellent agreement among interpreters and unfortunately, interpreter cross validation does not often occur during these type of studies. Therefore, we cannot compare our numbers to other sources in the literature.

Table D1. Polygons that were unambiguous have matching interpretations; polygons that are ambiguous had different interpretations (off-diagonal of the matrix). As an example, the 12 non-matching values can be interpreted as follows: interpreter 1 called 12 polygons false when interpreter 2 called those same polygons true.

		Interpreter 2		
		FALSE	TRUE	**Proportion unambiguous**
Interpreter 1	FALSE	206	12	0.94
	TRUE	10	24	0.70

The proportion of unambiguous disturbance polygons for the INDU analysis area was quite high. However, this simple statistic only takes into account the total number of polygons cross validated, and this figure is perhaps inflated because of the large number of false polygons. Figure D1 shows the total area of disturbance polygons both observers identified by change agent. We see very good apparent agreement between observers, with only a few hectares difference in total disturbance area identified.

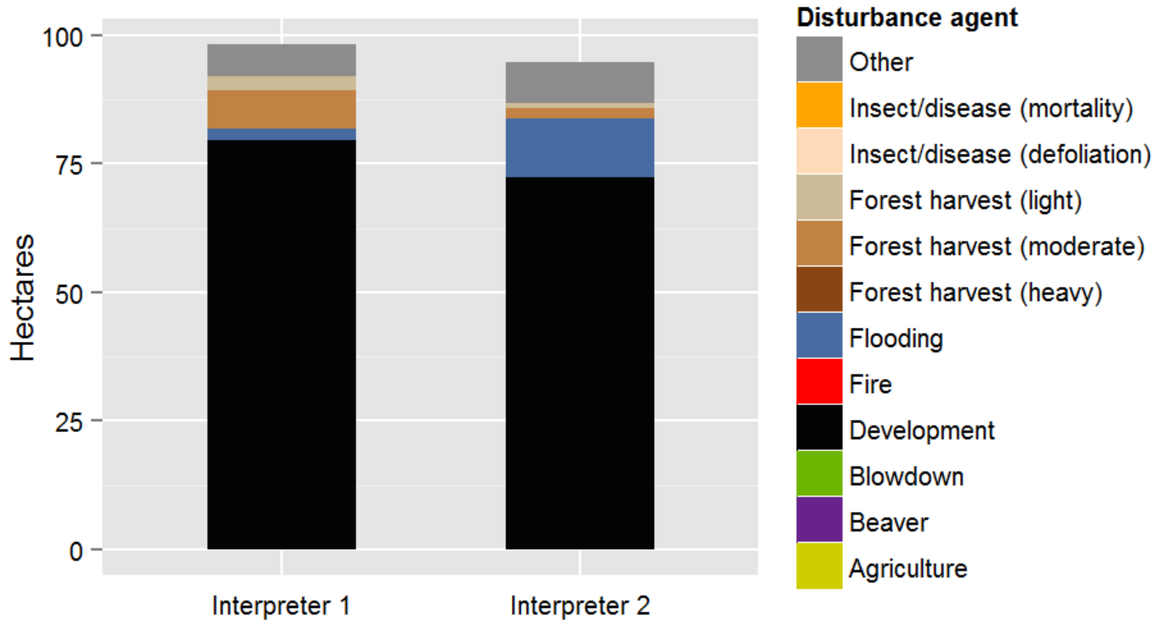

Figure D1. Area (ha) of land disturbed by disturbance agent as determined by each interpreter.

In figure D2, looking at the 24 polygons both interpreters determined were true, we can see that both interpreters generally agreed on the starting and ending classes of the polygons. Overall, this is excellent agreement between interpreters, starting class assignment is almost identical, with some disagreement for ending class in determining level of developed class and herbaceous class.

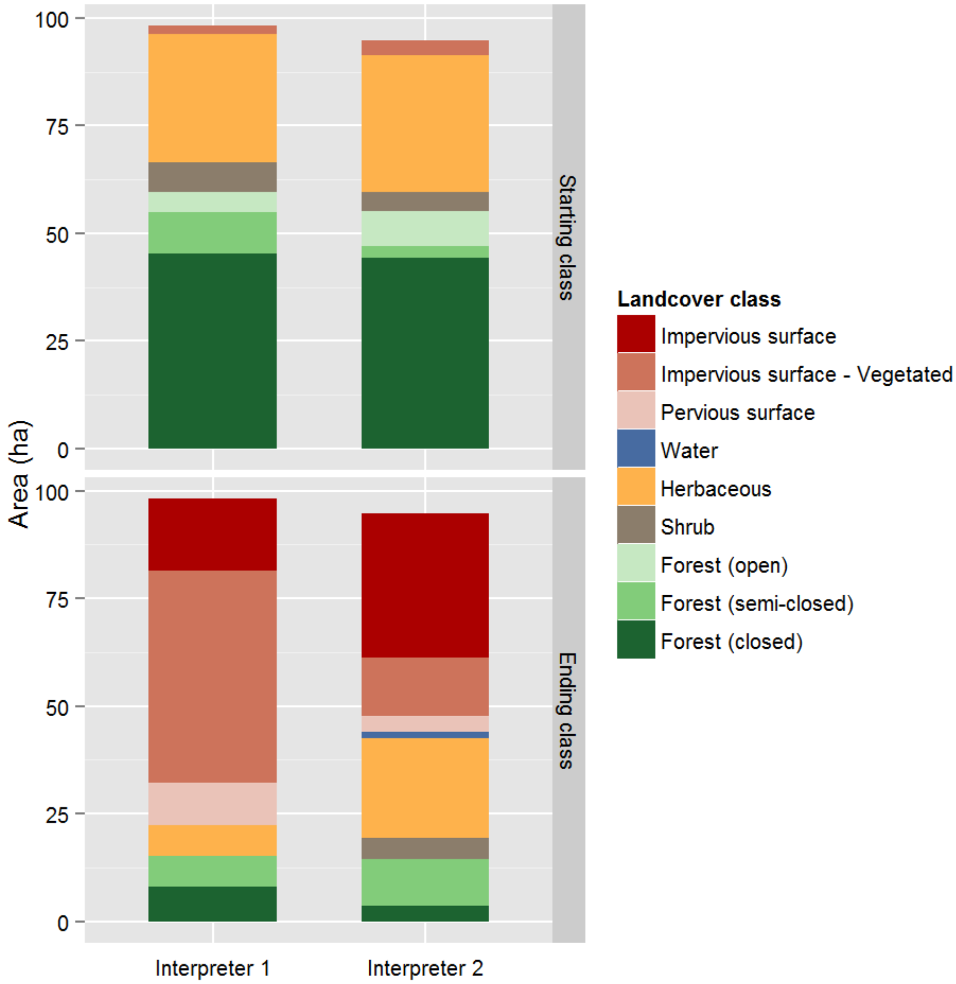

Figure D2. Area (ha) of land cover gained and lost as indicated by each interpreter.

Figure D3 shows the case where both interpreters determined the polygon was true. Here we see very good correlation between observers as to the change agent.

The majority of LandTrendr polygons were false disturbances. This occurs commonly on agricultural lands, with crop rotations showing very different reflectance year to year, or on herbaceous wetlands, ever-changing with phenology and degree of wetness. If we just look at those polygons where both observers called it true, there appears to be excellent agreement in assigning a change agent, (Figure D3).

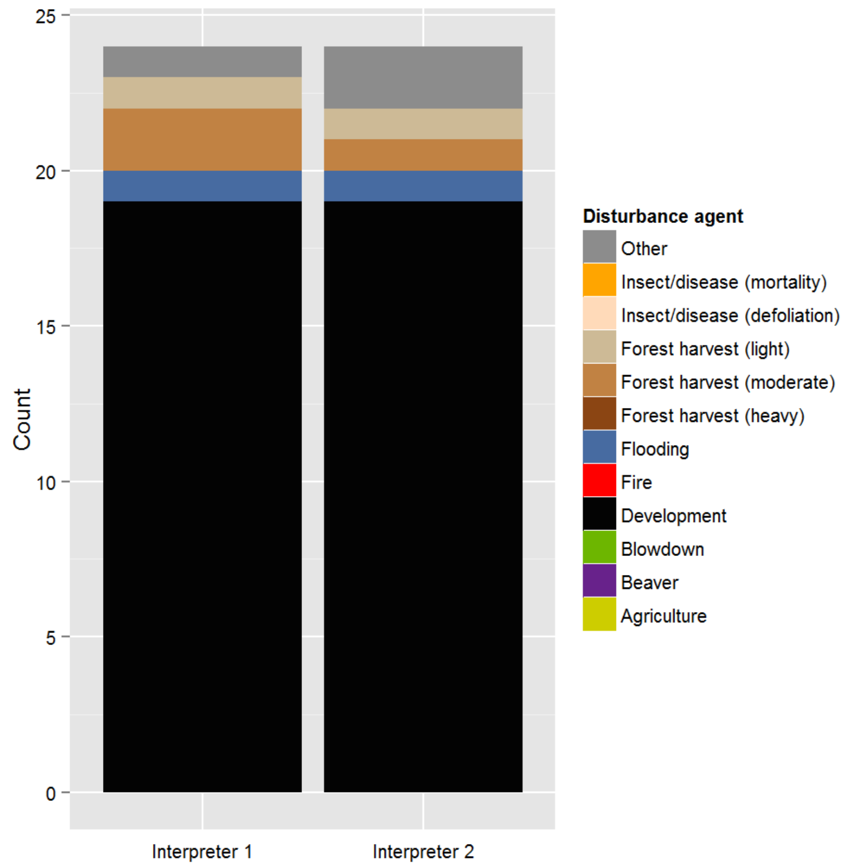

Figure D3. Change agent attributed when both observers agreed the polygon was true.

We also looked more closely at the polygons where the interpreters did not agree. If we examine the number of true/false determinations versus true/true, we see that the two interpreters agreed only 52% of the time. For example, of the 10 polygons interpreter 1 thought were true and interpreter 2 thought were false, what was the change agent responsible for the disturbance (first column, figure D4).

These differences are reviewed, and provide the observers opportunity to learn how to better apply various rules to improve consistency. For example, many of the discrepancies were disturbances attributed to development. In cases of disagreement, we found commonly minor changes, such as some trees removed in a suburban residential area. Interpreter 1 determined this was not a 'significant' change, whereas Interpreter 2 called it true. This prompts us to build a rule whereby developed class must change, as in from impervious-vegetated to impervious in order to qualify as a true disturbance.

Figure D5 summarizes the total area that these 'confused' polygons contribute to the overall cross-validation summary.

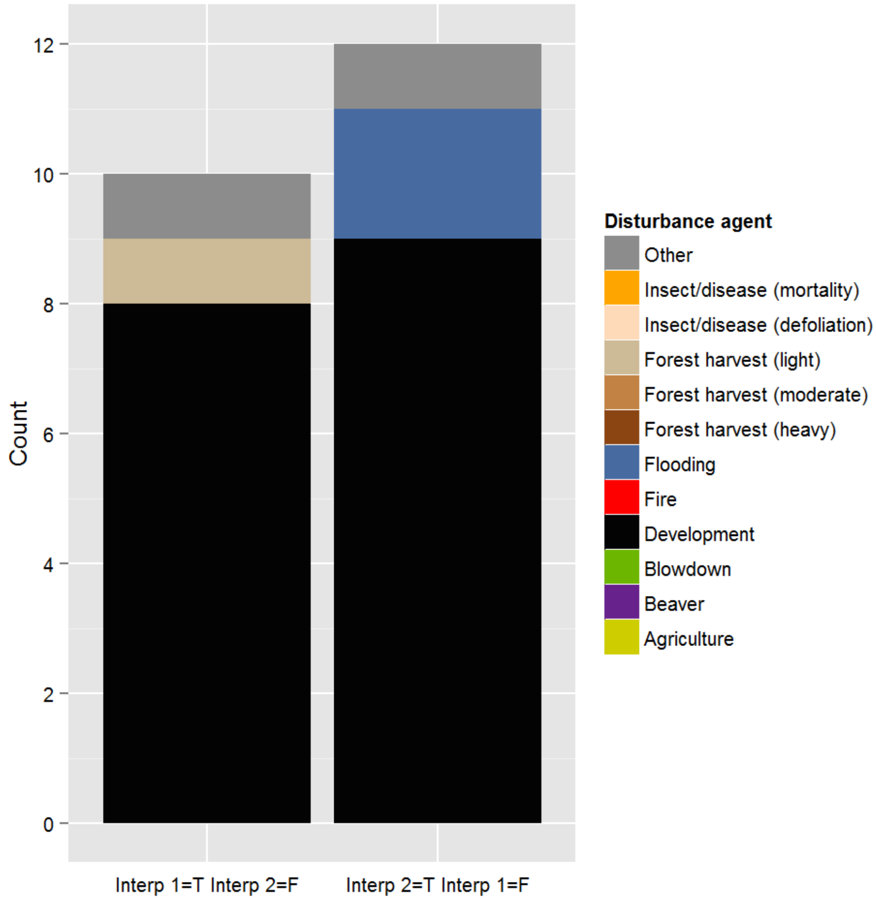

Figure D4. Count (n) of 'confused' polygons and the agent to which each interpreter attributed the change. For example, of the 17 polygons interpreter 1 thought were true and interpreter 2 thought were false, most of the polygons were classified as changed due to development.

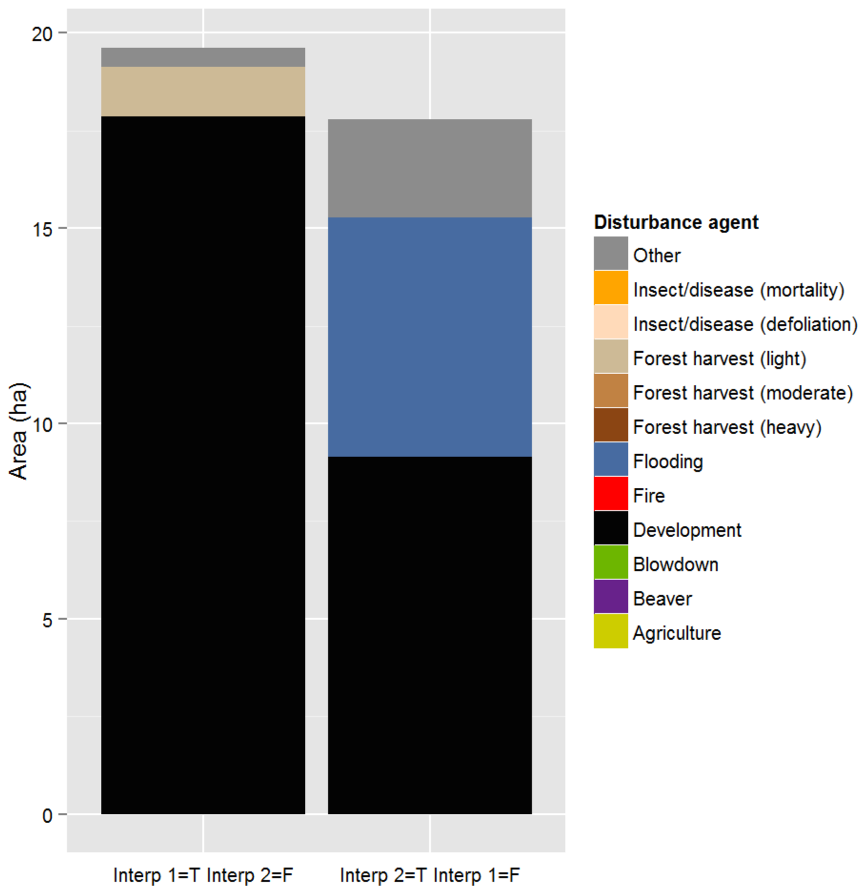

Figure D5. Same as figure D4, except using area instead of count affected.

Appendix E. Study Areas at Previous Parks.

As was mentioned previously, analysis areas for parks have varied from a simple buffer approach (VOYA, ISRO, PIRO) to including watersheds flowing into the park (APIS, SACN, MISS, SLBE).

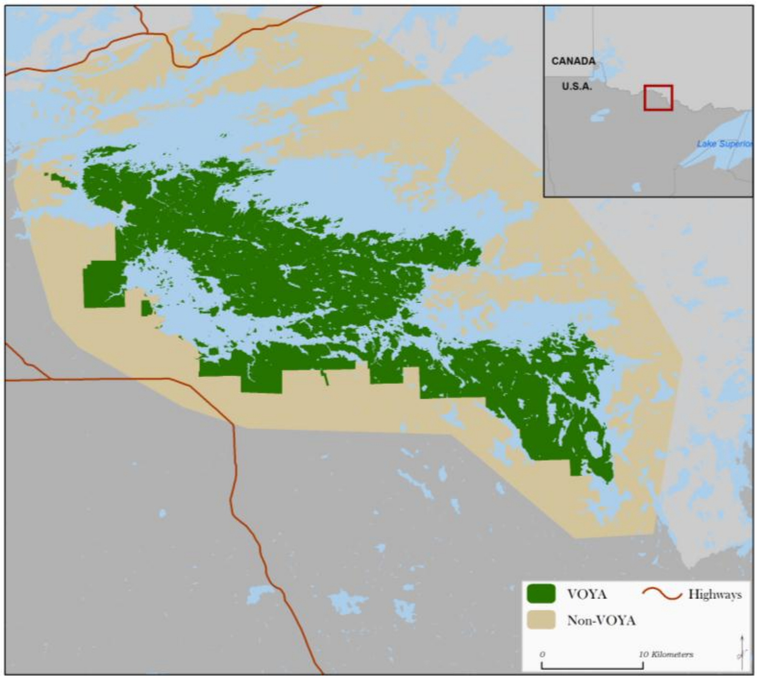

Figure E1. Analysis area for Voyageurs National Park (VOYA).

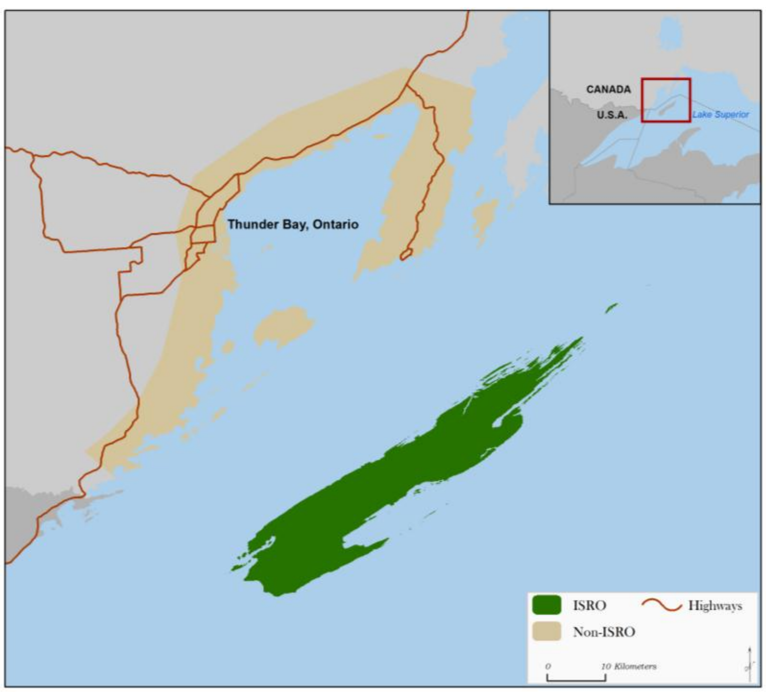

Figure E2. Analysis area for Isle Royale National Park (ISRO).

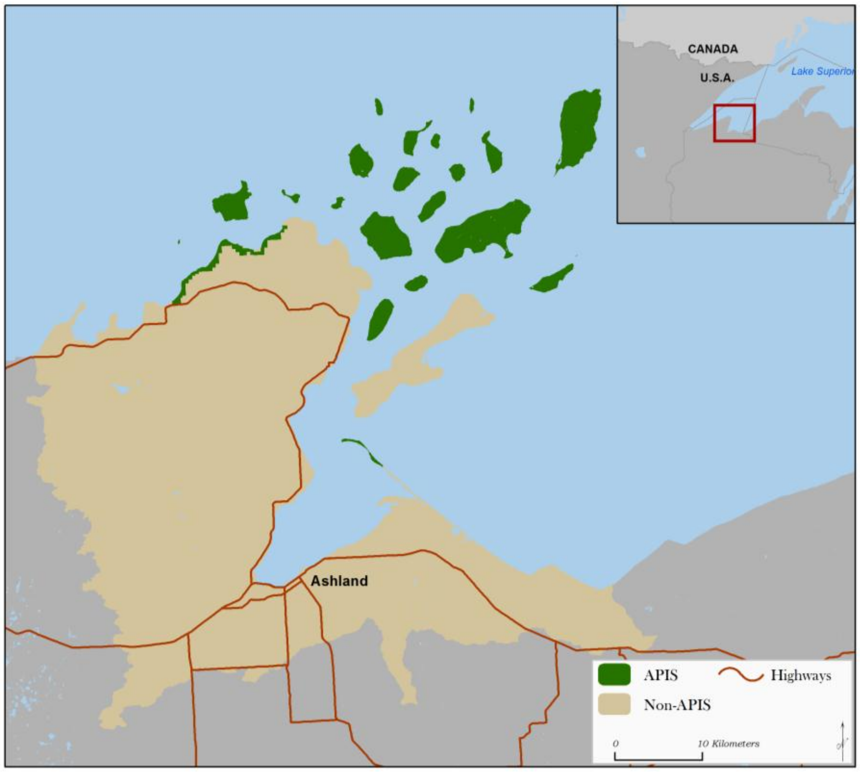

Figure E3. Analysis area for Apostle Islands National Lakeshore (APIS).

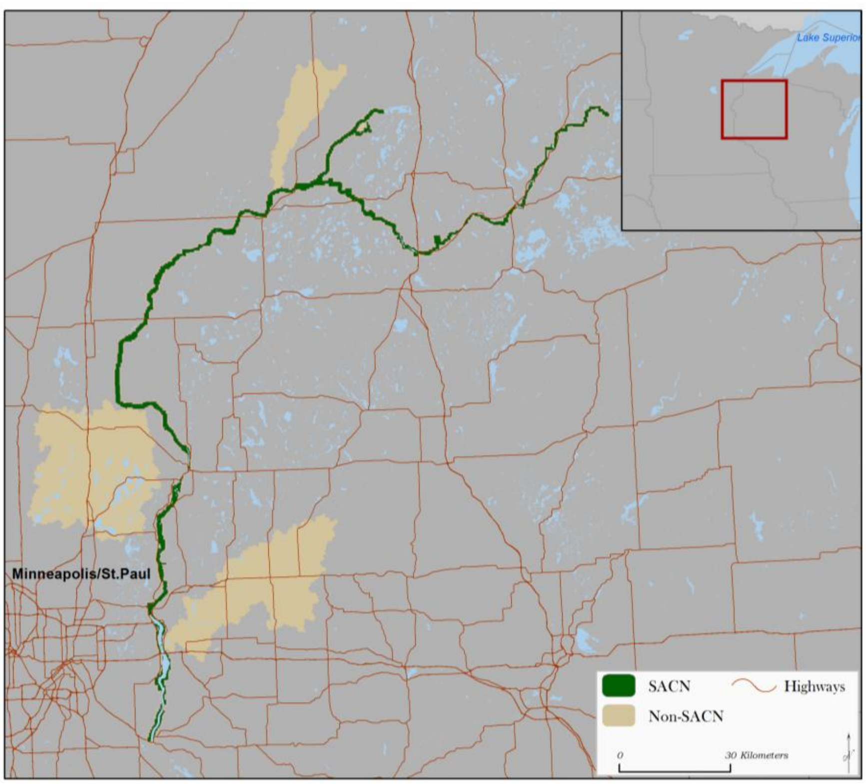

Figure E4. Analysis area for St. Croix National Scenic Riverway (SACN).

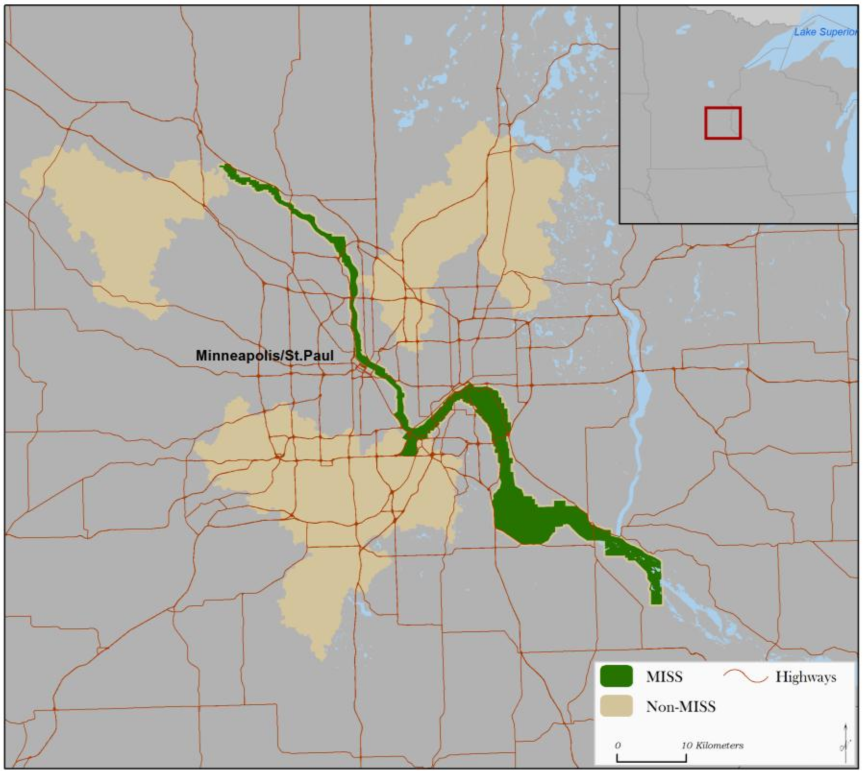

Figure E5. Analysis area for Mississippi National River and Recreation Area (MISS).

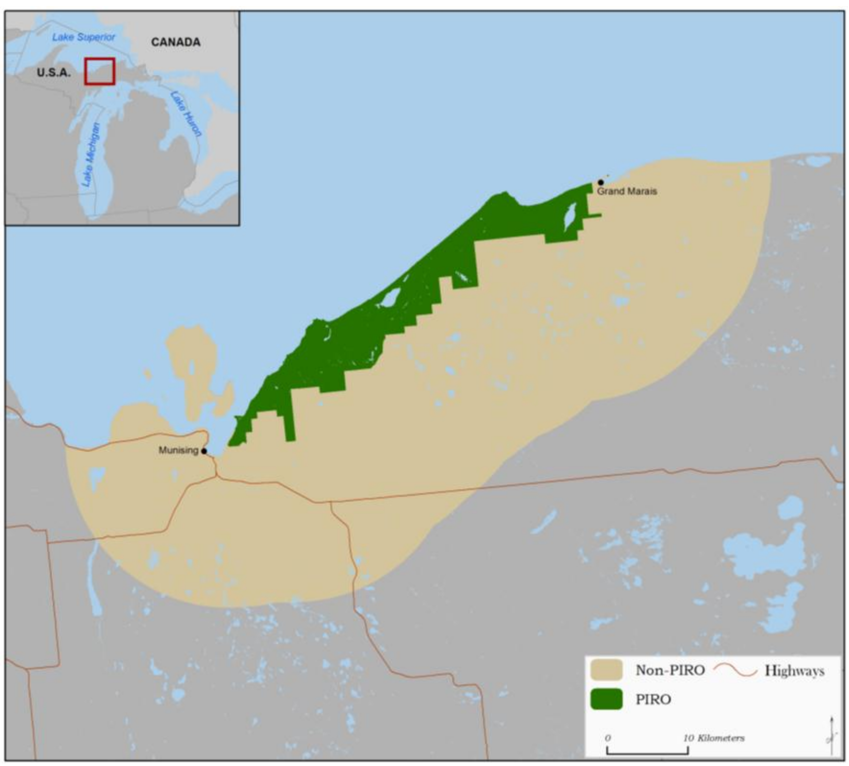

Figure E6. Analysis area for Pictured Rocks National Lakeshore (PIRO).

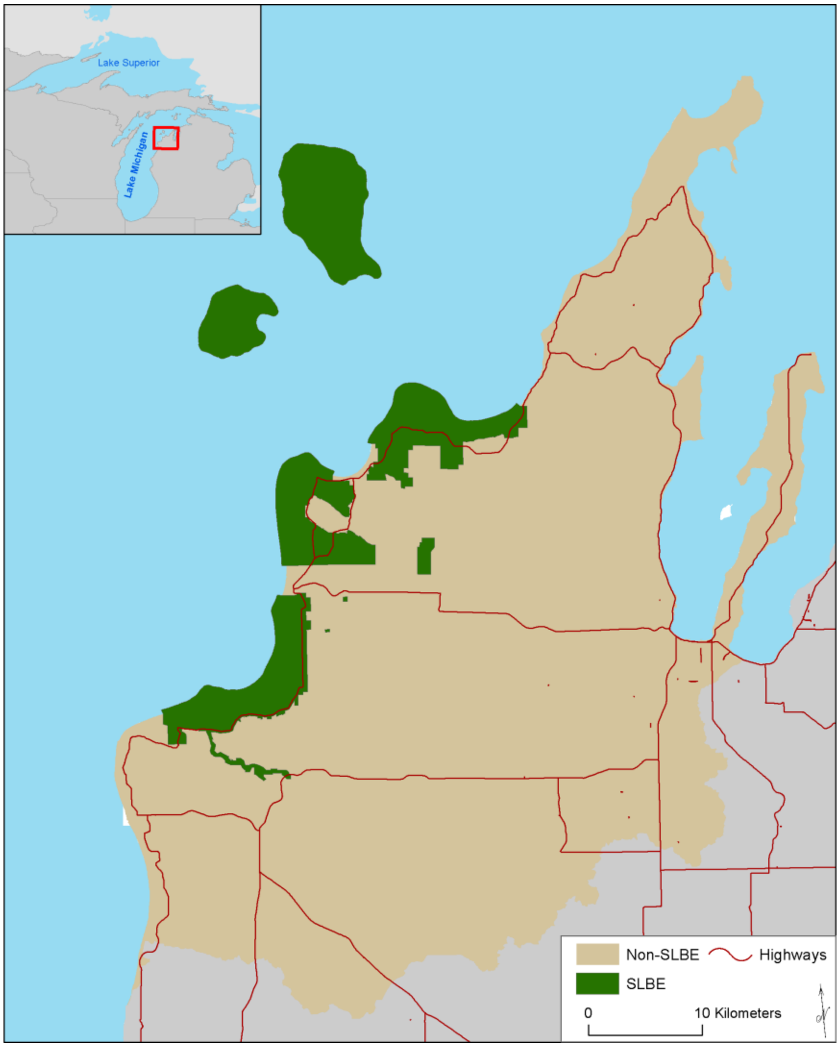

Figure E7. Analysis area for Sleeping Bear Dunes National Lakeshore (SLBE).

NPS 626/130356, November 2015

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U.S. Department of the Interior

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